TABLE 35. U.S. GEOLOGICAL SURVEY AND U.S. FOREST SERVICE SAMPLING STATIONS IN THE TONGUE RIVER

Station Number	Station Name	Latitude/ Longitude
USGS Stations		
06298000	Tongue River near Dayton, WY	44°50'58"/107°18'14"
06299980	Tongue River at Monarch, WY	44°54'08"/107°01'49"
06305500	Goose Creek below Sheridan, WY	44°49'25"/106°57'40"
06306100	Squirrel Creek near Decker, MT	45°03'05"/106°55'36"
06306300	Tongue River at State line near Decker, MT	45°00'32"/106°50'08"
06306800	Deer Creek near Decker, MT	45°03'19"/106°42'09"
06307500	Tongue River at Tongue River Dam, MT	45°08'29"/106°46'15"
06307600	Hanging Woman Creek near Birney, MT	45°17'57"/106°30'28"
06307610	Tongue River below Hanging Woman Creek, MT	45°20'19"/106°31'28"
06307615	Cook Creek near Birney, MT	45°22'39"/106°29'45"
06307670	Bear Creek at Otter, MT	45°12'20"/106°12'20"
06307740	Otter Creek at Ashland, MT	45°35'18"/106°15'17"
06307810	Beaver Creek near Ashland, MT	45°47'52"/106°14'17"
06307830	Tongue River below Brandenberg Bridge, MT	45°52'18"/106°11'17"
06307840	Liscom Creek near Ashland, MT	45°54'09"/106°09'51"
06308160	Pumpkin Creek near Loesch, MT	45°42'40"/105°43'50"
06308170	Little Pumpkin Creek near Volberg, MT	46°46'00"/105°46'42"
06308190	Pumpkin Creek near Volberg, MT	45°51'50"/105°40'10"
06308400	Pumpkin Creek near Miles City, MT	46°13'42"/105°41'24"
06308500	Tongue River at Miles City, MT	46°21'30"/105°48'24"
USFS Stations		
026301	South Tongue River at USGS 2970	44°47'02"/107°28'10"
026302	Sibley Lake at SW boat ramp	44°45'00"/107°26'00"
026303	Prune Creek above Sibley Lake	44°45'00"/107°26'00"
026305	North Tongue River near Burgess Ranger Station	44°47'00"/107°32'00"
026501	Big Goose Creek at USGS gage 3020	44°42'08"/107°10'51"
026503	Little Goose Creek at USGS 3035	44°35'46"/107°02'22"

TABLE 36. U.S. GEOLOGICAL SURVEY AND U.S. FOREST SERVICE SAMPLING STATIONS IN THE POWDER RIVER

Station Number	Station Name	Latitude/Longitude
USGS Stations		
06312500	Powder River near Kaycee, WY	43°41'35"/106°31'48"
06313000	South Fork Powder River near Kaycee, WY	43°37'10"/106°34'36"
06313400	Salt Creek near Sussex, WY	43°37'22"/106°22'00"
06313500	Powder River at Sussex, WY	43°41'53"/106°17'51"
06316400	Crazy Woman Creek at Upper Station, WY	44°29'15"/106°10'25"
06317000	Powder River at Arvada, WY	44°38'45"/106°08'00"
06320200	Clear Creek below Rock near Buffalo, WY	44°21'44"/106°39'13"
06320400	Clear Creek at Ucross, WY	44°33'09"/106°32'06"
06323500	Piney Creek at Ucross, WY	44°33'45"/106°32'25"
06324000	Clear Creek near Arvada, WY	44°52'18"/106°04'56"
06324500	Powder River at Moorhead, MT	45°04'04"/105°52'10"
06324925	Little Powder River near Weston, WY	44°38'51"/105°18'37"
06324970	Little Powder River above Dry Creek near Weston, WY	44°55'45"/105°21'06"
06326050	Mizpah Creek at Olive, MT	45°32'30"/105°31'40"
06326200	Mizpah Creek near Volborg, MT	45°56'00"/105°23'40"
06326300	Mizpah Creek near Mizpah, MT	46°15'39"/105°17'34"
06326500	Powder River near Locate, MT	46°26'56"/105°18'44"
USFS Stations		
026901	Rock Creek at USGS gage 3200 near Buffalo	44°34'50"/106°55'55"
027301	Clear Creek at USGS gage 3185	44°20'00"/106°46'10"

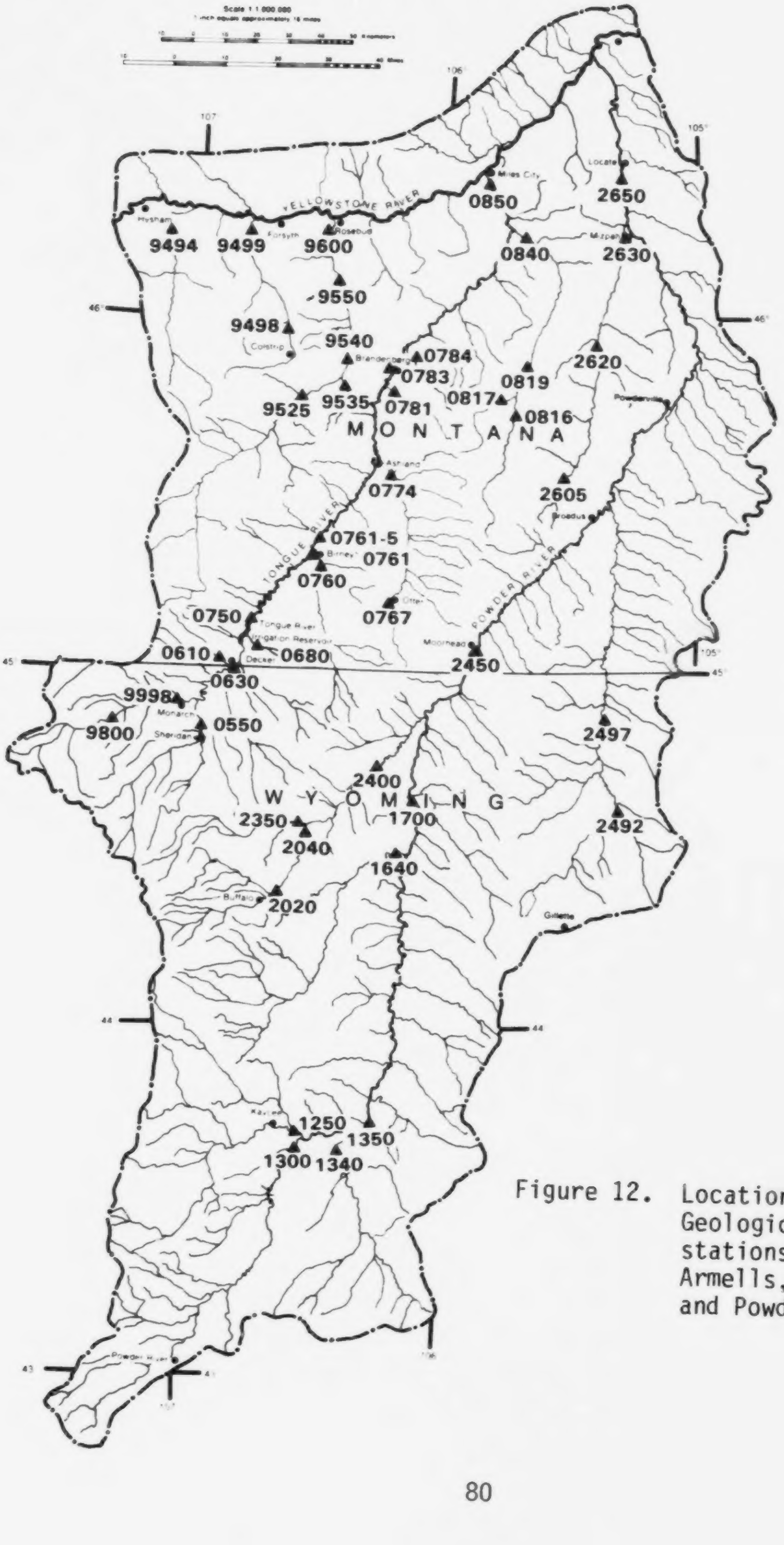
Scale 1:1 000 000
1 inch equals approximately 16 miles
Kilometers
Miles
107°
106°
105°
46°
45°
44°
43°
YELLOWSTONE RIVER
TONGUE RIVER
POWDER RIVER
MONTANA
WYOMING
Hysham
Forsyth
Rosebud
Miles City
Locate
Mizpah
Colstrip
Brandenberg
Ashland
Powderville
Broadus
Birney
Otter
Tongue River Irrigation Reservoir
Decker
Moorhead
Monarch
Sheridan
Buffalo
Gillette
Kaycee
Powder River
9494
9499
9600
0850
2650
0840
2630
9550
9498
9540
0784
0783
2620
0819
9525
9535
0781
0817
0816
0774
2605
0761-5
0761
0760
0767
0750
0610
0680
0630
2450
9998
9800
0550
2497
2400
1700
2350
2040
2492
1640
2020
1250
1350
1300
1340

Figure 12. Locations of U.S. Geological Survey sampling stations in the Sarpy, Armells, Rosebud, Tongue, and Powder River Basins.

occurs through irrigation return flows, natural sources, and municipal and industrial wastes. Salt concentrating, reduction of the amount of water available for dilution of the salts already present in the river system, results from consumptive uses of the water and from evaporation and transpiration losses. Of particular significance are salinity levels in the Powder River, which are among the highest in the entire Northern Great Plains region (Northern Great Plains Resource Program, 1974).

Ambient Levels--

Total dissolved solids (TDS) concentrations and conductivity levels provide an indication of the dissolved constituents present in water. Values for these two parameters (Appendix B), as well as concentrations of each of the major cations (calcium, sodium, magnesium, potassium) and anions (bicarbonate, sulfate, chloride) generally increased from upstream to downstream in the Tongue, Powder, and Rosebud Rivers (Table 37, Figure 13).

In the Tongue River, surface water sample data obtained in 1976 revealed an increase in average TDS concentration from 138 mg/l near Dayton, Wyoming, to 559 mg/l at Miles City, Montana. In the same stretch of river there was an average conductivity increase from 270 µmho/cm to 815 µmho/cm during 1976. In the Powder River, surface water samples showed an increase in average TDS concentration from 795 mg/l near Kaycee, Wyoming, to 1330 mg/l at Locate, Montana, in 1976. Rosebud Creek stations from near Colstrip, Montana, and at the mouth near Rosebud demonstrated increases in surface water conductivity levels from 1249 µmho/cm to 1463 µmho/cm, respectively, and increases in TDS levels from 807 mg/l to 991 mg/l for the same year.

In the upper reaches of the Tongue River, calcium is the major cation followed by magnesium, sodium, and potassium. In the lower basin, calcium and sodium codominate, followed by magnesium and potassium. The most abundant anion in the basin is the bicarbonate ion; however, in the lower basin, mean sulfate concentrations very nearly achieve levels equivalent to bicarbonate (Figure 13).

In the upper reaches of the Powder River, calcium is the major cation followed by sodium, magnesium, and potassium. In the lower basin near Locate, the sodium ion predominates. Sulfate is the major anion throughout the Powder River Basin, followed by bicarbonate and chloride; chloride concentrations are substantially higher in this basin than in any of the other drainage areas examined in this paper.

In Rosebud Creek, bicarbonate is the major anion in the basin followed by sulfate and chloride. The most abundant cation in the upper basin is the magnesium ion; in the lower basin the sodium ion predominates. Carbonate levels throughout the study area are quite low.

Basin geology is primarily responsible for upper to lower basin shifts in anion/cation dominances, as well as the distinct differences between ion

TABLE 37. DISTRIBUTION OF MAJOR CATIONS AND ANIONS AT SELECTED STATIONS IN THE TONGUE, POWDER, AND ROSEBUD RIVERS, 1974 AND 1976

Parameter	Tongue River near Dayton		Tongue River at Miles City		Powder River near Kaycee		Powder River at Locate		Rosebud Creek near Colstrip		Rosebud Creek at mouth	
	1974	1976	1974	1976	1974	1976	1974	1976	1974	1976	1974	1976
Conductivity (μmho/cm)	223	270	878	815	1334	-	2273	1879	1457	1249	1477	1463
TDS (mg/1)	133	138	549	559	941	795	1420	1330	821	807	933	991
Calcium (mg/1)	31	33	63	61	125	107	130	118	78	77	79	78
Sodium (mg/1)	2	2	58	65	109	94	263	246	70	69	106	114
Magnesium (mg/1)	12	12	44	43	49	39	59	51	94	90	93	99
Potassium (mg/1)	1	1	5	4	3	3	8	7	11	9	10	10
Bicarbonate (mg/1)	146	154	284	280	237	208	323	278	524	476	501	495
Sulfate (mg/1)	6	6	228	237	461	394	647	665	283	300	377	422
Chloride (mg/1)	2	1	4	4	61	43	143	96	5	5	6	6

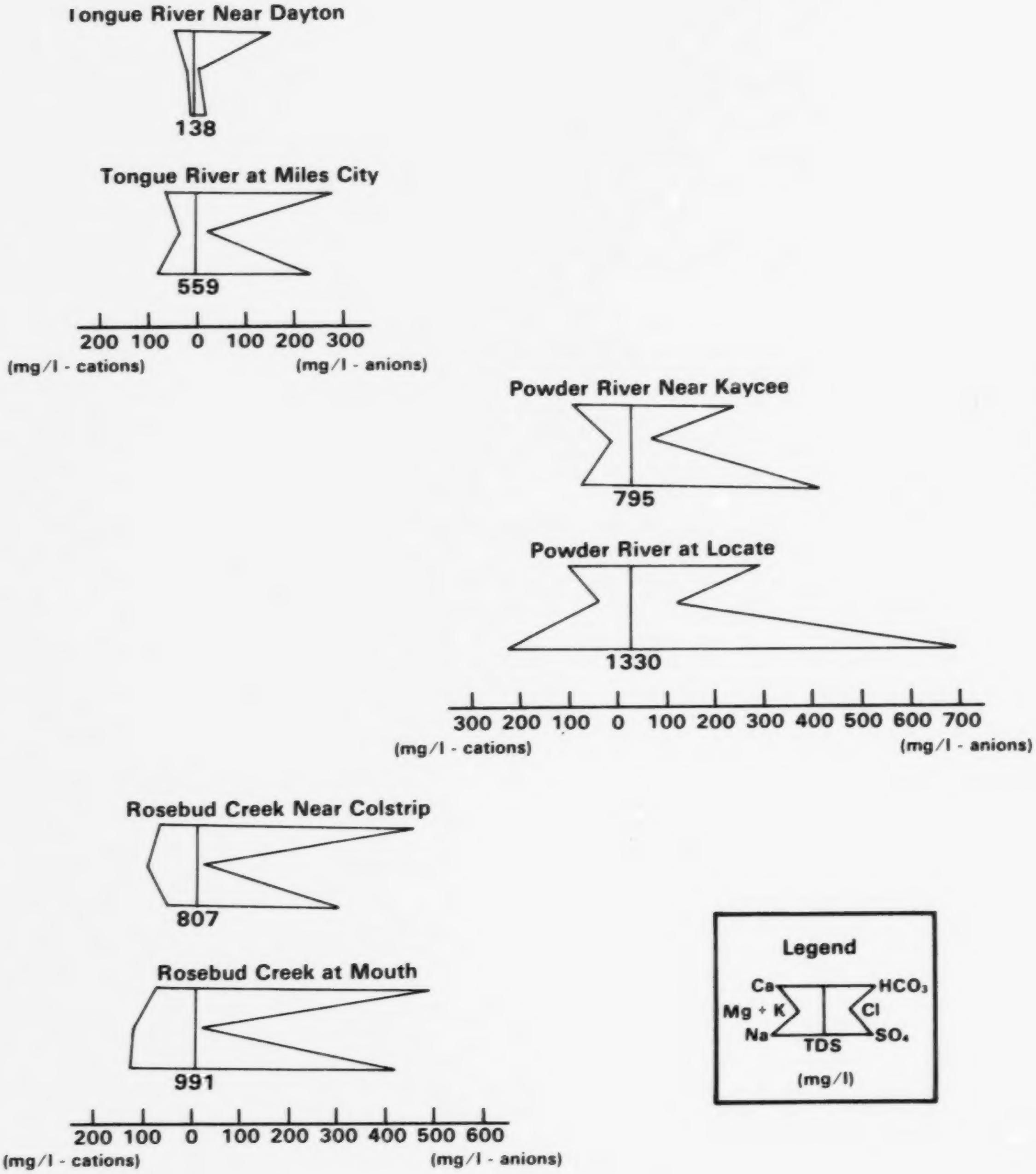

Figure 13. Distribution of major cations and anions at selected stations in the Tongue, Powder, and Rosebud River Basins, 1976.

composition among the river basins (Figure 13) in this study area. Knapton and McKinley (1977) state:

> "The variations described above in streamflow, water types, and dissolved solids concentrations in Rosebud Creek are primarily a function of the basin geology and in part seem to be associated with geologic formations. Changes in water type seem to be more prevalent where the channel intersects the Hell Creek Formation between the two downstream stations. The abnormal consistency in dissolved solids concentration between the middle stations occurred where the stream has eroded through the Lebo and Tullock Members of the Fort Union Formation."

In all of the study basins except for Rosebud Creek, the ionic composition of the base flow waters (ground water) is a sodium sulfate type (Knapton and McKinley, 1977). Sodium sulfate dominance is characteristic of waters flowing through clay materials and shale, both of which are prevalent in drainages of the Fort Union Formation. An increase in ground-water contribution to the surface flow of this area is reflected by the increasing levels of sodium sulfate in downstream waters of the basins (Knapton and McKinley, 1977).

In the upstream reaches of the tributaries, surface runoff from snowmelt or rain make up a greater percentage of the flow, and ionic composition is generally dominated by calcium bicarbonate or magnesium bicarbonate with low concentrations of total dissolved solids (Knapton and McKinley, 1977). Sodium and sulfate ions leach out of surface soils to the deep soil zones and are more readily available to subsurface waters than surface flows. Calcium and magnesium are thus left as the most soluble cations in the surface soils. The shift to anion dominance by bicarbonate is probably the result of biochemical activity within surface soils reacting with carbon dioxide provided by the atmosphere (Knapton and McKinley, 1977).

Both the concentrations and composition of dissolved solids in the study tributaries vary with flow. Ion concentrations tend to increase as flow decreases; chemical composition generally shifts from calcium bicarbonate dominance, during high flow periods when surface water is the main contributor to flow, to sodium sulfate dominance during medium and low flows (Knapton and McKinley, 1977). Fluctuations in flow play a major role in the large seasonal variations of dissolved solids concentrations observed in the basins, tending generally to be high during low runoff times and low during periods of high flow. In the Tongue River, changes in water types below the Tongue River Reservoir are also the result of water releases from the dam. If water stored in the reservoir before release has been primarily from base flow, or ground water, then water below the dam tends to be of the magnesium sulfate or magnesium bicarbonate type (Knapton and McKinley, 1977). If the base flow component in storage has been mixed with a large percentage of spring runoff, water releases tend to be of a calcium bicarbonate type. It is interesting to note that in the Tongue River at Miles City water type is highly variable and does not seem to be clearly correlated with either total dissolved solids levels or flow (Knapton and McKinley, 1977).

Sources--

Man's industrial activities increase TDS levels primarily through salt loading processes. Oil field operations substantially increase salinity levels in the Powder River Basin. Segments of the Powder River below its confluence with Salt Creek, a stream that consists mainly of wastewater from oil field operations, are classified as problem areas because of high salt concentrations (Missouri River Basin Commission, 1978a). In 1978, Salt Creek added 47 percent of the salinity recorded in the Powder River at Sussex; the Missouri River Basin Commission (1978a) reports that most oil treaters on Salt Creek are in compliance with permit discharge requirements, and thus salinity levels in the Powder River are not likely to decrease in the near future unless permit requirements were to be reevaluated and modified to maintain higher water quality in the Powder River Basin.

Mining also increases TDS levels through salt loading. Wangsness (1977) showed that ponds formed in abandoned open mining pits near Sheridan contained salt levels as much as an order of magnitude higher than control ponds outside of the old mining area. Studies done in the vicinity of Bighorn Mine, Wyoming (Dettman et al., 1976), indicate that concentrations in Goose Creek are 50 percent higher than those in the Tongue River upstream from the mine, although they are qualitatively similar. In particular, samples from mine discharges showed large increases in sodium and sulfate concentrations over ambient river levels. However, the impact of mining discharges in this area is highly dependent upon surface discharge levels. During periods of high flow, pumped mine effluents to the Tongue River are greatly diluted, and less severely affect the river water quality than in times of low river discharge during late summer and fall. Dettman et al. (1976) report "While present water quality impacts of the Bighorn Mine are probably small and variable, substantial expansion activities along the river could result in significant water quality impacts." The same could be said of all mining activities in the study basins.

Irrigation activities increase salinity levels in the basins. It is estimated (Northern Great Plains Resource Program, 1974) that as much as 60 percent of the total water applied for irrigation may be lost to evapotranspiration. Since this lost water is salt free, the net effect of this concentration can be over twofold increases in salt levels in the irrigation return flows. Irrigation contributions to salinity through the salt loading process vary with areal soil type, subsurface geology, and use of fertilizers or other agricultural chemicals (Northern Great Plains Resource Program, 1974). In the vicinity of Hysham on Sarpy Creek and in the Tongue River Basin near Miles City, improper irrigation practices also contribute to problem ground-water salinity levels (Yellowstone-Tongue Areawide Planning Organization, 1977). Discharge of this saline water to surface drainages, particularly during seasonal low flow, is another irrigation-related source of water quality degradation in the basins. The Yellowstone-Tongue Areawide Planning Organization (1977) anticipates that eventually irrigation return flow permits will be required by agricultural users in the region in an attempt to reduce return flow salinity impacts.

Finally, the construction of supplemental reservoirs on the Tongue and Powder Rivers may have some impact on water quality. Alterations of instream flow regimes will be the greatest impact; dams will change the Powder and upper Tongue Rivers from free-flowing to regulated discharges. Overall water quality, however, is not anticipated to be greatly affected by additional impoundments if they are properly constructed. Deep reservoirs with low surface-area-to-volume ratios, such as the present Tongue River Reservoir, typically exhibit little influence on water quality other than to reduce the variability of parameters downstream. For example, the annual average increase in conductivity from USGS stations in the Tongue River at the Montana-Wyoming State line to just below the reservoir was only 1 µmho, and dissolved solids levels actually fell from a mean value of 453.8 mg/l to 434.8 mg/l (based on STORET data from 1975 to present). On the other hand, shallow reservoirs with low surface-to-volume ratios may have large relative evaporation rates and result in substantial increases in salinity and temperature in downstream waters. Careful consideration of reservoir sites, resultant reservoir hydrography, and projected impact on water quality should be made prior to approval of construction.

Impact--

The EPA water quality criterion for both chlorides and sulfates (Table 38) in domestic water supplies is 250 mg/l (U.S. Environmental Protection Agency, 1976b). The sulfate criterion was imposed because of the anion's cathartic effect especially when associated with magnesium and sodium. Chloride levels in excess of the 250 mg/l criterion, particularly in association with calcium and magnesium, tend to produce problems in corrosiveness. Both cations affect water taste when present in concentrations in excess of 300 to 500 mg/l (U.S. Environmental Protection Agency, 1976b).

The sulfate criterion has been exceeded between 1974 and 1977 at every USGS station in the study area except for Greenleaf Creek near Colstrip, the Tongue River stations near Dayton, and at Monarch, Fourmile Creek near Birney, and Liscom Creek near Ashland. At all these stations water flows only intermittently in response to snowmelt and rainfall; fast runoff over frozen ground allows limited dissolution to occur, so water is characteristically calcium bicarbonate type with low sulfate concentrations. Chloride levels in excess of the EPA criterion were reported at only six USGS stations, all of which are in the Powder River Basin: Armells Creek near Forsyth, Clear Creek at Arvada, South Fork Powder River near Kaycee, Salt Creek near Sussex, and Powder River stations at Moorhead, Sussex, and Arvada. The highest chloride levels were reported at the Salt Creek site, with concentrations in excess of 1,000 mg/l commonly observed.

The State of Montana has initiated a salinity standard of 500 mg/l in the Tongue River at the Wyoming-Montana State line (Personal communication, C. Murray, U.S. EPA, Denver, Colorado, 1978). Data collected by the USGS (Appendix B) show mean annual TDS concentrations ranging from 416 mg/l to 520 mg/l during the years 1970-77. If the standard of 500 mg/l is to be met, significant impact to the agricultural industry in Wyoming, and perhaps to mining activities in the vicinity of Sheridan, can be expected.

TABLE 38. WATER QUALITY CRITERIA RECOMMENDED BY THE NATIONAL ACADEMY OF SCIENCE (1973)[*]

Parameter (total form)	Criteria For Drinking Water (mg/l)	Livestock (mg/l)	Aquatic Life (mg/l)	Irrigation (mg/l)
Aluminum	--	5.0	--	5.0
Arsenic	0.05[†]	0.2	--	0.1[††]
Barium	1.0[†]	--	--	--
Beryllium	--	--	0.011-1.100[††]	0.1-0.5[††]
Boron	--	5.0	--	0.75[††]
Cadmium	0.01[†]	0.05	0.0004-0.012[††]	0.01
Chlorides	250[††]	--	--	--
Chromium	0.05[†]	1.0	0.1[††]	0.1
Copper	1.0[††]	0.5	AF[†††]	0.2
Cyanide	0.2	--	0.005[††]	--
Dissolved Oxygen	--	--	5.0	--
Fluoride	1.4-2.4[†]	2.0	--	1.0
Iron	0.3[††]	--	1.0[††]	5.0
Lead	0.05[†]	0.05-0.1	0.03	5.0
Lithium	--	--	--	2.5
Manganese	0.05[††]	--	--	0.2
Mercury	0.002[†]	0.01	0.05 μg/l[††]	--
Molybdenum	--	--	--	0.01
Nickel	--	--	AF	0.2
Nitrate nitrogen	10.0[†]	100.0	--	--
Nitrite nitrogen	1.0	10.0	--	--
pH	5.0-9.0	--	6.5-9.0	--
Selenium	0.01[†]	0.05	--	0.02
Silver	0.05[†]	--	--	--
Sulfates	250[††]	--	--	--
Vanadium	--	0.1	--	0.1
Zinc	5.0[††]	25.0	AF	2.0

[*] Those parameters for which drinking water regulations (1975) or quality criteria (1976b) have been established by the U.S. Environmental Protection Agency are specially indicated, and in this table replace the older NAS recommended levels.

[†] U.S. Environmental Protection Agency (1975).

[††] U.S. Environmental Protection Agency (1976b).

[†††] AF = Application factor. Indicates criterion for this parameter must be separately established for each water body.

Tables of water hardness in the study basins are presented in Appendix B. Sawyer's classification of water according to hardness content (U.S. Environmental Protection Agency, 1976b) is given in Table 39.

TABLE 39. SAWYER'S CLASSIFICATION OF WATER ACCORDING TO HARDNESS CONTENT

Concentration of $CaCO_3$ (mg/l)	Description
0 - 75	Soft
75 - 150	Moderately hard
150 - 300	Hard
300 and up	Very Hard

Source: Modified from U.S. Environmental Protection Agency (1976b).

By this classification, Greenleaf Creek in the Rosebud River Basin and Liscom Creek in the Tongue River Basin are the only soft-water streams in the study area. The Tongue and Powder Rivers progress from moderately hard at their headwaters to very hard near Miles City and Locate, respectively. Stations in Sarpy, Armells, and Rosebud Creek Basins, except for Greenleaf Creek, are classified as very hard. It should be noted that these hardness classifications are based on mean annual values, but within a given stream there is frequently large variation in hardness content across time. This variability is largely associated with changes in ion dominance resulting from periods of high runoff. For example, stations such as the Tongue River at Miles City, which are basically hard water and sodium sulfate in composition, become soft during high flow periods when calcium replaces sodium as the dominant cation.

High salinity concentrations and hard water have several adverse effects on municipal needs aside from lowering drinking water quality. If water softening is not practiced, soap and detergent consumption increases, resulting in increased nutrients and other environmental pollution, and treatment costs rise with the degree of hardness. Dissolved solids and hardness also play a role in corrosion, scaling of metal water pipes and heaters, and acceleration of fabric wear (U.S. Environmental Protection Agency, 1976b).

Descriptions of the impact of total dissolved solid concentrations on irrigation waters in arid and semiarid areas are presented in Table 40 (U.S. Environmental Protection Agency, 1976b). Mean annual TDS values for Greenleaf Creek, the Tongue River stations at Dayton, Monarch, and below Hanging Woman Creek, Goose Creek, Liscom Creek, Fourmile Creek, and the North Fork Powder River stations below Johnson City and above Gardner (Appendix B) have not been in excess of the 500 mg/l limit for the time period 1970-77. Mean annual TDS levels in excess of 2,000 mg/l (i.e., water that can be used only for tolerant plants on permeable soils) have been reported at many stations including Armells and Pumpkin Creeks, Mizpah Creek at Olive and Volborg, Deer, Otter, Beaver, and Salt Creeks, the Powder River at Sussex, and the South Fork Powder River at Kaycee. However, information on some of the tributaries, such as Greenleaf, Fourmile, and Liscom Creeks, is based on very limited data.

TABLE 40. TOTAL DISSOLVED SOLIDS HAZARD FOR IRRIGATION WATER (mg/l)

Description	TDS
Water from which no detrimental effects will usually be noticed	500
Water that can have detrimental effects on sensitive crops	500-1,000
Water that may have adverse effects on many crops and requires careful management practices	1,000-2,000
Water that can be used for tolerant plants on permeable soils with careful management practices	2,000-5,000

Source: Modified from U.S. Environmental Protection Agency (1976b).

Variability about the mean TDS levels is primarily influenced in the study basins by the degree of surface runoff. During spring and early summer periods of high flow, surface flows are dominated by water from rainfall and snowmelt and TDS levels are typically low. Later in the year, flows are reduced, ground water flowing to the surface comprises a larger percentage of the available surface flow, and TDS levels are increased. Those reaches of the tributaries subject to ponding also increase total dissolved solid levels through evaporation and transpiration. Knapton and McKinley (1977) report that the lowest reported TDS level in Otter Creek (228 mg/l) actually resulted in the highest loading (160,539 kg/day) because of the high discharge of the period. In the Tongue River, some variability in total dissolved solid concentrations can also be attributed to periodic dam closures (Knapton and McKinley, 1977).

Excessive salinity in irrigation water reduces crop yields, limits the types of crops grown in an area, and can affect soil structure, permeability, and aeration (U.S. Bureau of Reclamation, 1975). Salt adversely impacts plants primarily by decreasing osmotic action and thereby reducing water uptake. Most of the land in the study area is used for agricultural purposes, with abundant cattle and sheep grazing and alfalfa, hay, and sugar beets the major irrigated crops (Knapton and McKinley, 1977). However, high salinity levels restrict the variety of crops that can be suitably grown in the basins, and in a number of the smaller tributaries flood irrigation is able to be practiced only along stream channels during high runoff periods when total dissolved solids and sulfate levels are substantially reduced.

The effects of salinity on irrigation are determined, not only by the total amount of dissolved solids present, but also by the individual ionic composition of the water (Utah State University, 1975). Certain plants are sensitive to high concentrations of sulfates and chlorides. Large amounts of calcium can inhibit potassium uptake. Sodium causes plant damage at high concentrations because it increases osmotic pressure and is toxic to some metabolic processes. It can also affect soils adversely by breaking down granular structure, decreasing permeability, and increasing pH values to those of alkaline soils. In 1954 the U.S. Salinity Laboratory proposed that the sodium hazard in irrigation water be expressed as the sodium absorption ratio (SAR), $\mathrm{SAR} = \mathrm{Na}/\sqrt{\tfrac{1}{2}(\mathrm{Ca} + \mathrm{Mg})}$ where Na, Ca, and Mg are expressed as concentrations in milliequivalents per liter of water (McKee and Wolf, 1963).

Sodium levels are high throughout much of this report's study area. The National Academy of Sciences (1973) suggested 270 mg/l as the maximum recommended sodium level in drinking water supplies. Mean sodium levels (Appendix B) in many of the intermittently flowing tributaries in both the Tongue and Powder River Basins, such as Deer, Pumpkin, and Mizpah Creeks, generally exceed this recommended level, as do sodium concentrations in the Powder River mainstem below Sussex. Sodium absorption ratios are highly variable throughout the basin and range from low to very high: the maximum value reported in STORET was SAR = 50 at Salt Creek near Sussex. The sodium hazards for most of the tributaries examined in this area were low to moderate.

Throughout much of the study area, such as in Anmells Creek, water is used almost exclusively for stock-watering purposes. Total dissolved solid concentrations in the basins are not generally restrictive to livestock (Table 41) although sulfate levels are near restrictive in some cases. Almost all the tributaries studied have numerous small stock pond dams in their upper drainages that are factors in flow regulation and sporadic release of ions during high runoff (Knapton and McKinley, 1977).

TABLE 41. TOTAL DISSOLVED SOLIDS HAZARD FOR WATER USED BY LIVESTOCK (mg/l)

TDS Content in Water (mg/l)	Comment
<1,000	Relatively low level of salinity. Excellent for all classes of livestock and poultry.
1,000-2,999	Very satisfactory for all classes of livestock and poultry. May cause watery droppings in poultry or temporary and mild diarrhea in livestock not accustomed to such TDS levels.
3,000-4,999	Satisfactory for livestock but may cause temporary diarrhea or be refused at first by animals not accustomed to them. Poor waters for poultry, often causing water feces, increased mortality, and decreased growth, especially in turkeys.
5,000-6,999	Can be used with reasonable safety for dairy and beef cattle, for sheep, swine, and horses. Avoid use for pregnant or lactating animals. Not acceptable for poultry.
7,000-10,000	Unfit for poultry and probably for swine. Considerable risk in using for pregnant or lactating cows, horses, or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.
>10,000	Risks with these highly saline waters are so great that they cannot be recommended for use under any conditions.

Source: Modified from National Academy of Sciences (1973).

Industrial users may be severely affected through use of water for cooling or washing purposes that is high in total dissolved solids. Such water may result in corrosion and encrustation of the metallic surfaces of pipes, condensers, or other machinery parts. However, industrial requirements for purity of water vary considerably (Table 42). Examination of TDS levels in Rosebud Creek, the Wyoming portions of the Tongue River Basin, and a few of the uppermost stations in the Powder River Basin (Appendix B) indicate that most industrial needs could be met in those areas without any water treatment efforts. However, at the remaining stations, mean annual TDS levels tend to be in excess of 1,500 mg/l and some form of deionization would be required for some industrial uses. This could be a primary factor limiting future industrial advancement in the study area.

The impact of salinity on fish and wildlife is highly variable. Many fish, for example, tolerate a wide range of total dissolved solid concentrations; the whitefish can reportedly survive in waters containing TDS levels as high as 15,000 mg/l, and the stickleback can survive in concentrations up to 20,000 mg/l (U.S. Environmental Protection Agency, 1976b). However, the U.S. Environmental Protection Agency (1976b) reports that generally water systems with TDS levels in excess of 15,000 mg/l are unsuitable for most freshwater fish. In the Tongue and Powder River Basin areas, TDS levels are well below this recommended maximum figure.

TABLE 42. MAXIMUM TOTAL DISSOLVED SOLIDS CONCENTRATIONS OF SURFACE WATERS RECOMMENDED FOR USE AS SOURCES FOR INDUSTRIAL WATER SUPPLIES

Industry/Use	Maximum Concentration (mg/l)
Textile	150
Pulp and paper	1,080
Chemical	2,500
Petroleum	3,500
Primary metals	1,500
Copper mining	2,100
Boiler makeup	35,000

Source: Modified from U.S. Environmental Protection Agency (1976b).

Toxic Substances

Trace Elements--

The primary source of trace elements in the Tongue and Powder River watersheds is surface runoff following thunderstorms. The Missouri River Basin Commission (1978a) reported the following observation from a water quality assessment of the 1976 water year:

> "Segments of the Powder River are affected primarily by high levels of sediment, salinity, and trace metals due to natural runoff and erosion. This is particularly evident at Arvada, where excesses of Cd, Cr, Hg, and Fe criteria occur during periods of high runoff."

Knapton and McKinley (1977) also cite numerous instances in the Rosebud and Tongue Rivers to demonstrate that high trace element concentrations in those drainages are associated with periods of highest flow and suspended sediment concentrations.

Energy development may influence trace element levels in several ways. Additional trace elements, particularly iron, aluminum, manganese, cobalt, nickel, and zinc, may be added to the river through runoff from strip mine tailings and coal storage (Wewerka et al., 1976) or through erosion of soils in disrupted areas. Table 43 presents the elemental composition of coal from a number of fields throughout the western energy development region, including coal from the Rosebud seam and the Powder River Basin.

Although none of the energy developers in the study basins are discharging untreated waste waters directly to surface or ground water systems, indirect runoff of effluents released from evaporative ponds to ground water or through overflow during storms pose a significant potential water quality threat (University of Oklahoma and Radian Corporation, 1977a). Reduction of water quantity from the developments and irrigation projects may also result in increased trace element concentrations in basin waters. Furthermore, trace elements in stack emissions from future coalfired powerplants, particularly copper, mercury, cadmium, zinc, lead, arsenic, and selenium, may be deposited in the drainage basins and can then reach the river through runoff (Northern Great Plains Resource Program, 1974).

Mercury concentrations in surface water samples from 1974 to 1977 exceeded the EPA's recommended criterion for aquatic life (Table 38) at all five of the Rosebud Creek stations and at most of the USGS stations in the Tongue and Powder Rivers. Maximum concentrations were highest in the Rosebud Creek stations below Rosebud and at the mouth (1.2 μg/l), at Clear Creek near Arvada (2.0 μg/l), at Little Powder River above Dry Creek (1.4 μg/l), and at the South Fork Powder River near Kaycee (2.1 μg/l). The Environmental Protection Agency (1976b) aquatic life criterion of 0.05 μg/l for mercury in water was established to insure safe levels in edible fish; the Clear Creek and South Fork Powder River stations were also in excess of recommended EPA criteria for mercury levels in drinking water. Those beneficial uses impacted by mercury and other trace element levels in excess of recommended criteria throughout the Tongue and Powder River study area are presented in Table 44.

TABLE 43. ELEMENTAL COMPOSITION OF COAL (mg/kg) FROM A NUMBER OF COAL FIELDS THROUGHOUT THE WESTERN ENERGY DEVELOPMENT AREAS

	Navajo Coal, Arizona	Navajo Overburden, Arizona	3 - NGP Coals	Black Mesa Field, Arizona	Rosebud Seam, Montana	Powder River Basin Composite, Montana	Powder River Basin Composite, Wyoming	Green River Basin, Wyoming	Hanna Basin, Wyoming	Wadge, Colorado	Wasatch Plateau, Utah
Ag		<5	0.03-0.05	-	-	0.01	0.03	0.03	0.04	-	-
Al			7,000-25,000	7,300	17,000	5,100	4,900	16,000	15,000	18,200	7,200
As	1.2	2.0	0.8-8.0	1.3	1.2	1.0	0.82	1.7	3.9	0.50	0.50
Au	<0.1										
B	75.	41	31-150	17	92	32	28	74	49	140	-
Ba	140.	717	130-460	-	-	600	360	160	430	-	-
Be	3.4	<1	0.3-0.8	0.20	1.0	<0.10	0.15	0.34	0.30	0.80	0.40
Bi	<0.1	<30									
Br	1.7			4.0	20	0.90	1.7	2.5	1.2	19	23
Ca			1,000-2,000	24,700	16,500	13,000	18,000	34,000	9,900	6,200	9,300
Cd	0.7	<10	<0.1-0.2	<0.2	<0.4	<0.10	<0.10	<0.20	<0.10	<0.4	<0.2
Ce	15.0			-	-	2.8	14	19	30	-	-
Cl			9.4-55	100	200	100	100	200	100	200	300
Co	1.6	23	0.8-2	7.0	2.0	0.71	1.8	2.0	2.8	2.0	1.0
Cr	4.6	16	9-21	5.0	5.0	7.0	11	15	20	5.0	7.0
Cs	0.2			-	-	0.14	0.05	0.80	0.20	-	-
Cu	44.0	40	10-34	22	18	10	12	16	23	10	11
Dy	0.7			-	-	0.39	0.66	1.0	1.3	-	-
Er	0.2										
Eu	0.5			-	-	0.10	0.22	0.33	0.42	-	-
F	210.0	417	57-140	39	42	50	46	85	120	110	50
Fe			2,000-8,000	5,500	6,000	5,000	3,000	4,000	7,000	3,400	4,800
Ga	12	27		1.6	3.5	1.1	1.6	6.5	2.9	3.7	1.6
Gd	<0.3										
Ge	0.9	<10		2.0	3.0	<0.10	<0.10	1.0	0.30	3.0	1.0
Hf	0.4			-	-	0.34	0.77	0.87	1.1	-	-
Hg	0.01	0.06	0.07-0.14	0.06	0.09	0.13	0.63	0.12	0.10	0.02	0.04
Ho	<0.1										
I	0.4			-	-	<0.50	0.47	<0.3	<0.3	-	-
Ir	<0.1										
In				-	-	<0.02	0.07	0.12	0.14	-	-
K				200	1,100	100	100	1,000	1,000	1,200	200
La	10.0			-	-	2.5	4.3	9.3	11	-	-
Li	85.0	83									
Lu				-	-	0.05	0.07	0.10	<0.03	-	-

(Continued)

TABLE 43. (Continued)

	Navajo Coal, Arizona	Navajo Overburden, Arizona	3 - NGP Coals	Black Mesa Field, Arizona	Rosebud Seam, Montana	Powder River Basin Composite, Montana	Powder River Basin Composite, Wyoming	Green River Basin, Wyoming	Hanna Basin, Wyoming	Wadge, Colorado	Wasatch Plateau, Utah
Mg			2,000-4,000	700	2,300	400	1,200	1,700	1,300	900	300
Mn	130	455	24-170	6.0	100	14	41	150	48	12	<8.0
Mo	4.9	<10	0.6-4	2.0	30	2.0	0.40	0.30	1.0	2.0	1.0
Na				890	200	2,700	6,000	100	100	280	2,000
Nb	5.6	<20									
Nd											
Ni		19	2-9	5.0	4.0	3.1	4.8	6.4	6.8	3.0	4.0
Os	<0.1										
P				130	48	92	150	150	510	400	80
Pb	5.5	36	0.9-4.2	4.0	7.0	0.95	1.3	5.0	5.0	5.0	4.0
Pd	<0.1										
Pr	3.4										
Pt	<0.1										
Rb	4.6			-	-	0.30	<1.0	9.0	13	-	-
S			4,400-7,200	4,200	11,100	7,200	6,400	6,900	12,400	5,500	6,900
Sb	0.4	0.5	0.01-0.5	0.3	0.90	0.44	0.20	0.76	0.39	0.2	0.2
Sc	4.0	10		-	-	1.0	2.1	3.9	4.5	-	-
Se	0.7	<0.5	1.3-2.2	1.2	0.80	0.87	2.3	2.4	2.1	1.0	1.2
Si				12,500	30,900	5,300	5,500	31,000	23,000	33,200	19,900
Sm	0.7			-	-	0.39	0.70	1.4	0.36	-	-
Sn	1.4	<5		-	-	<0.10	<0.20	<0.4	<0.3	5.0	-
Sr	53	133		-	-	390	200	160	280	-	-
Ta	0.4			-	-	0.04	0.11	0.33	0.26	-	-
Tb				-	-	0.08	0.36	0.20	0.58	-	-
Te	0.2										
Th	3.6			-	-	0.62	1.9	4.4	5.4	-	-
Ti			350-1,100	500	600	500	500	700	1,000	600	600
Tl				-	-	-	-	-	-	-	-
U	0.7		0.9-1.5	-	-	<1.0	0.76	2.5	2.4	-	-
V	21.0	35	15-51	17	14	11	14	4.0	43	14	11
W	6.9			-	-	0.76	0.13	0.66	0.73	-	-
Y	13.0										
Yb				-	-	0.13	0.43	0.67	0.52	-	-
Zn	12	38	4-24	15	12	2.0	3.0	5.0	17	7.0	1.3
Zr	140	142		-	170	14	22	24	30	25	74

Note: Blanks indicate no analysis, - indicates analysis attempted, element was below detection limits.

TABLE 44. PARAMETERS EXCEEDING EPA (1976b) OR NATIONAL ACADEMY OF SCIENCES (1973) WATER QUALITY CRITERIA, 1974-77, AT U.S. GEOLOGICAL SURVEY STATIONS IN SARPY, ARMELLS, ROSEBUD, TONGUE, AND POWDER RIVER BASINS

Station Number*	Cadmium**	Iron	Lead**	Manganese	Mercury	Sulfates	Aluminum	Chromium	Fluoride	Dissolved Oxygen	Copper	Beryllium
Sarpy Creek												
9494	AL,DW,I	AL,DW,I	AL,DW,L†	DW,I	AL	DW				AL		
Armells Creek												
9498	AL,DW,I	AL,DW	AL,DW,L†	DW,I	AL	DW						
9499	AL,DW,I	AL,DW,I	AL,DW,L†	DW,I	AL	DW	I,L	DW			I	AL†
Rosebud Creek												
9525	AL†,DW,I	AL,DW,I	AL,DW,L†	DW,I	AL	DW	I,L					
9535	AL†,DW,I	AL,DW	AL,DW,L†	DW	AL							
9540	AL,DW,I	AL,DW,I	AL,DW,L†	DW,I	AL	DW						
9550	AL†,DW,I	AL,DW,I	AL,DW,L†	DW,I	AL	DW	I,L					
9600	AL,DW,I	AL,DW,I	AL,DW,L†	DW,I	AL	DW						
Tongue River												
9800	AL†,DW,I	DW	AL,DW,L†	DW	AL							
9998	AL†,DW,I	AL,DW	AL,DW,L†	DW								
0550	AL†,DW,I	AL,DW	AL,DW,L†	DW	AL	DW	I,L					
0610	AL†,DW,I	AL,DW,I	AL,DW,L†	DW	AL	DW		DW				
0630	AL†,DW,I	AL,DW	AL,DW,I†	DW,I	AL	DW						
0680	AL,DW,I	AL,DW,I	AL,DW,I	DW,I	AL	DW		DW				
0750	AL†,DW,I	DW	AL,DW,L†	DW	AL	DW						
0760	AL,DW,I	AL,DW,I	AL,DW,L†	DW,I	AL	DW						
0761	AL†,DW,I	AL,DW	AL,DW,L†	DW	AL	DW			I			
0761-5	AL,DW,I	AL,DW	AL,DW,L†	DW	AL	DW						
0767	AL†,DW,I	AL,DW	AL,DW,L†	DW		DW						
0774	AL†,DW,I	AL,DW	AL,DW,L†	DW,I	AL	DW		DW		AL		
0781	AL,DW,I	AL,DW	AL,DW,L†	DW		DW						
0783	AL†,DW,I	AL,DW,I	AL,DW,L†	DW,I	AL	DW	I,L					
0784	AL†,DW,I	AL,DW	AL,DW,L†									
0816	AL†,DW,I	AL,DW	AL,DW,L†	DW,I		DW				AL		
0817						DW						
0819	AL†,DW,I	DW	AL,DW,L†	DW		DW						
0840	AL,DW,I	AL,DW	AL,DW,L	DW	AL	DW						
0850	AL,DW,I	AL,DW,I	AL,DW,L†	DW,I	AL	DW		DW				

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*For full description of stations, see Tables 34-36. Beneficial use codes are designated as follows: AL=aquatic life, DW=drinking water, L=livestock, I=irrigation.

**Most observed concentrations are below detection range; minimum detection value, however, exceeds indicated criteria.

†Values reported greater than the criterion range lowest value.

TABLE 44. (Continued)

Station Number*	Cadmium**	Iron	Lead**	Manganese	Mercury	Sulfates	Aluminum	Chromium	Flouride	Dissolved Oxygen	Copper	Beryllium
Powder River												
1250						DW						
1300	AL,DW,I,L	AL,DW,I	AL,DW,L	DW,I	AL,DW	DW	I,L	AL,DW,I			I,L	AL†
1340	AL,DW,I	AL,DW,I	AL,DW,L	DW,I	AL	DW	I,L	AL,DW,I		AL	I	AL†
1350	AL,DW,I	AL,DW,I	AL,DW,L†	DW		DW	I,L					
1640	AL†,DW,I	AL,DW,I	AL,DW,L†	DW		DW						
1700	AL†,DW,I	AL,DW,I	AL,DW,L	DW,I	AL	DW	I,L	AL,DW,I		AL	I	AL†
2020	AL†,DW,I	AL,DW	AL,DW,L†	DW	AL	DW						
2040	AL†,DW,I	AL,DW	AL,DW,L†	DW		DW						
2350	AL†,DW,I	DW	AL,DW,L†	DW	AL	DW						
2400	AL†,DW,I	AL,DW,I	AL,DW,L	DW,I	AL,DW	DW	I,L					
2450	AL,DW,I	AL,DW,I	AL,DW,L	DW,I	AL	DW	I,L	AL,DW,I		AL	I,L	AL†
2492	AL†,DW,I	AL,DW,I	AL,DW,L†	DW,I	AL	DW						AL†
2497	AL†,DW,I	AL,DW,I	AL,DW,L	DW,I	AL	DW	I,L	AL,DW,I				AL†
2605	AL†,DW,I	DW	AL,DW,L†	DW,I		DW				AL		
2620	AL,DW,I	DW	AL,DW,L†	DW,I	AL	DW				AL		
2630	AL,DW,I	AL,DW,I	AL,DW,L	DW,I	AL	DW	I,L	AL,DW,I				AL†
2650	AL,DW,I	AL,DW,I	AL,DW,L	DW,I	AL	DW		AL,DW,I		AL	I	
	Chloride	Nickel	Selenium	Zinc	Boron	Molybdenum	Arsenic					
1300	DW	I	DW,I	I			DW,I					
1340	DW	I										
1350	DW											
1700	DW	I	DW									
2400					I							
2450	DW	I		I			DW,I,L					
2492					I	I						
2497						I	DW					
2650	DW						DW					

Concentrations of iron in the study area are highly variable. Nevertheless, from 1974 to 1977 iron levels were reported in excess of the EPA criterion for drinking water at every USGS station examined except for Little Pumpkin Creek at Volberg and the Powder River at Kaycee. The criterion was established to prevent objectionable taste and laundry staining (U.S. Environmental Protection Agency, 1976b). Iron levels throughout the basins quite frequently exceeded the recommended criteria for aquatic life and irrigation waters as well. High concentrations of iron can be fatal to aquatic organisms. Mine drainage, ground water, and industrial wastes are major sources of iron pollution.

Manganese concentrations were also highly variable. However, similar to iron, manganese levels frequently exceeded the EPA standard for domestic water supplies at all but the stations at Liscom Creek near Ashland, Little Pumpkin Creek near Volborg, and the Powder River near Kaycee. The 50.0-μg/l criterion was established to minimize staining of laundry and objectionable taste effects. The objectionable qualities of manganese may increase in combination with low concentrations of iron (U.S. Environmental Protection Agency, 1976b).

Barium, silver, and fluoride were only rarely sampled; the latter was, however, once reported in the Tongue River below Hanging Woman Creek at a value in excess of the irrigation water criterion (Table 44) and has also been reported in high concentrations in ground water samples in the area (Yellowstone-Tongue Areawide Planning Organization, 1977). Lead was reported throughout the basins at levels in excess of recommended drinking water, aquatic life, and livestock criteria. Cadmium values equal to or in excess of criteria for aquatic life, drinking water, and irrigation were frequently reported. Maximum concentrations of several trace elements in the Powder River Basin, including arsenic, beryllium, copper, nickel, selenium, zinc, boron, and molybdenum, were occasionally equal to or in excess of recommended criteria (Table 44). Aluminum levels periodically exceeded livestock and irrigation water criteria at 13 USGS stations throughout the study basins. Chromium (valence 6) concentrations were in excess of drinking water criteria at four stations throughout the Tongue River Basin, once in Armells Creek, and in excess of aquatic life and irrigation standards as well as drinking water criteria at seven stations in the Powder River Basin. A complete listing showing the number of times parameters exceeded recommended criteria at USGS stations throughout the study area, as well as the maximum value observed for these parameters, is included in Appendix C.

Pesticides--

Data on pesticides in the study area covered by this report are very limited. Samples have been collected by the USGS in the Powder River at Moorhead, but no data are available for the Tongue River Basin or other tributaries in the region. More information is needed before an accurate evaluation of conditions can be made; however, it might be expected that additional pesticides will be contributed to the river system as a result of proposed irrigation projects.

Radioactive substances--

Radioactive elements are not a problem in the surface waters of the study area at this time; recent concentrations of radioactive substances are generally below the Environmental Protection Agency (1976a) Drinking Water Regulations for radionuclides (Table 45).

TABLE 45. U.S. ENVIRONMENTAL PROTECTION AGENCY DRINKING WATER REGULATIONS FOR SELECTED RADIONUCLIDES

Radionuclide	Allowable Level* (pCi/l)
Tritium (H_3)	20,000
Strontium-90	8
Radium-226,228 (combined)	5
Gross alpha (excluding radon and uranium)	15

*No specific limits for allowable concentrations have been set for radionuclides not shown on this table. For these, it is merely specified that their combined dose should not exceed 4 mrem per year to the whole body or to any internal organ.

Source: Modified from U.S. Environmental Protection Agency (1976a).

Suspended Sediments

Suspended sediments are those organic and mineral materials that are released to a watershed from a combination of channel erosion and overland runoff and that are maintained in suspension by turbulent currents or through colloidal suspension. During periods of high flow, bank erosion is escalated and the greater water velocities provide increased energy for scouring and transport of sediments. Many inorganic elements such as trace metals are adsorbed onto moving sediment particles making suspended sediments an important transport mechanism (Knapton and McKinley, 1977). Sediment levels are also important because of their potential impact on light penetration, water temperature and chemical solubility, and aquatic biota (such as abrasive action on aquatic life or the elimination of benthic habitats and spawning areas by settleable solids that blanket the streambeds). In the Tongue and Powder River Basin areas, suspended sediment concentrations vary greatly from drainage to drainage (Appendix B).

Suspended sediments in Armells Creek are lower than in most tributaries of the study area. This can be attributed to 1) dense aquatic vegetation lining the river channel, which reduces bank erosion; 2) numerous upstream stock ponds and natural pools that trap sediments except during very high runoff times; and 3) seasonal frozen ground conditions (Knapton and McKinley, 1977). Maximum suspended sediment concentrations in Sarpy Creek are also much lower than sediment data from streams further east in the study area because of frozen ground conditions, stock pond impoundments, and irrigation practices; in both tributaries, suspended sediment levels correlate directly with flow. In Rosebud Creek, sediment movement is more variable. There can be seen, however, a striking increase between sediment levels in Rosebud Creek above Pony Creek and those at the two stations at Rosebud and the stream mouth (Knapton and McKinley, 1977).

The Missouri River Basin Commission (1978a) reports that substantial water quality degradation occurs in the Tongue River between Dayton and Monarch, largely as a result of naturally high turbidity and sediment levels that are somewhat increased by agricultural and livestock grazing activities. Mining operations near Sheridan, Wyoming, and in Montana near Decker have also resulted in some localized sediment problems to the Tongue River (Northern Great Plains Resource Program, 1974). Further downstream, suspended sediment concentrations in the Tongue River are largely regulated by the Tongue River Reservoir. The impoundment acts as a sediment sink, and those constituents carried in suspension are settled out and at least temporarily lost to the stream (Knapton and McKinley, 1977). Water released from the dam is essentially sediment free and so has a high carrying capacity that keeps the upstream channel flushed; the Montana Department of Natural Resources and Conservation (1977) reports that because of the Tongue River Reservoir the Tongue River now contributes only a very small part of the sediment load to the mainstem Yellowstone River. During periods of high rainfall, suspended sediment concentrations are elevated. Sediment levels are also augmented by overland runoff in the basin, particularly after thunderstorm activity following long dry periods (Knapton and McKinley, 1977).

Runoff from surrounding plains that are underlain by easily erodable sedimentary rock is the source of most sediment transported by the Powder River and its tributaries (Knapton and McKinley, 1977). Like the other watersheds in this area, sediment discharge to the drainage is erratic and a factor of intermittent periods of rainfall or seasonal high runoff. The Powder River and Mizpah Creek had the highest trace element concentrations to be found in the study area and these concentrations were largely associated with levels of suspended sediments that were also higher than those found in other streams (Knapton and McKinley, 1977). The Montana Department of Natural Resources and Conservation (1977) reports that the Powder River contributes only 5 percent of the mainstem Yellowstone's water but nearly one-half of its sediment load.

Nutrients

Nutrient levels in the study basins are generally low except during periods of high runoff from snowmelt and storms. Nitrogen levels tend to demonstrate a cyclic pattern in the basins, with wintertime increases and low summer concentrations (Knapton and McKinley, 1977). Ammonia levels are especially elevated at some stations; a possible explanation is winter decomposition of organic materials under ice cover. In the summer months stream aquatic vegetation is dense, and nutrients tend to be removed from water by the plants during the time of peak productivity. Highest total phosphorus levels are apparently correlated with highest suspended sediment concentrations during periods of surface runoff (Knapton and McKinley, 1977).

Nitrogen levels, particularly ammonia, in Armells Creek are higher than in any of the other study streams; those elevated ammonia levels may indicate the influence of upstream contributions of waste effluent (Knapton and McKinley, 1977). High nutrient levels in this stream contribute to heavy aquatic vegetation growth, particularly in the upper reaches of the tributaries where ponding is common.

Tongue River Reservoir has been classified as eutrophic by the Environmental Protection Agency (1977c). During the 1975 sampling, the median total phosphorus value in the reservoir was 0.051 mg/l; the median inorganic nitrogen level was 0.050 mg/l and the median dissolved orthophosphorus was 0.008 mg/l. Of the 15 Montana lakes and reservoirs sampled by the National Eutrophication Survey in 1975, all had lower median total phosphorus and eight had lower median orthophosphorus than Tongue River Reservoir. Of the estimated annual total phosphorus loading of 133,530 kg/yr, 75 percent was contributed by nonpoint loading from the Tongue River and 11.1 percent was contributed by the municipal sewage treatment plant at Sheridan. If the current loading continues, problem algal and macrophyte growths may result.

Agricultural runoff and sewage are major sources of nutrient loadings. Any future irrigation projects could contribute additional nutrients to basin waters. The Powder River Areawide Planning Organization (1977) has reported that several streams in Wyoming, including Goose Creek below Sheridan, Tongue River below Goose Creek, Little Powder River, South Fork of the Powder River, mainstem Powder River near Montana, Little Goose Creek from Bighorn to the confluence with Big Goose Creek, and Big Goose Creek from above Sheridan to the confluence with Little Goose Creek, are unable to meet fishable-swimmable water quality criteria because of excess ammonia or fecal coliform concentrations. Increased sewage and urban runoff, a result of the expected population expansion from proposed irrigation projects and energy developments, could further increase nutrient concentrations in the river if not carefully controlled. High ammonium and nitrate nitrogen levels are being released to the Tongue River from the Bighorn Mine, probably as a result of the use of ammonium nitrate explosives during coal extractions (Dettman et al., 1976). Coal gasification may also produce nitrogen in the form of ammonia as a commercial byproduct.

Temperature

Temperature is a parameter of significance to the stability of aquatic systems. It controls the geographical dispersal of biotic communities, is related to ambient concentrations of dissolved gases, and affects the distribution of chemical solutes in lentic water bodies through the phenomenon of stratification. Of particular interest in the Tongue and Powder River Basins are variations in temperature as they relate to fisheries of the area. Changes from a cold-water to a warm-water fishery occurs if temperatures are directly lethal to adults or fry, cause a reduction in activity, or limit reproduction (U.S. Environmental Protection Agency, 1976b).

Mean temperature values generally increase from upstream to downstream in the Tongue and Powder Rivers and their tributaries (Appendix B). Raw data trends for temperature in the study basins indicate that water temperature is generally highest in July, August, and September and lowest during December, January, and February. The Montana Department of Natural Resources and Conservation (1976a) reports that increased depletion of water in the Tongue River for irrigation needs, even at low projected levels, will result in water temperature increases likely to negatively impact the trout fisheries of that basin.

Dissolved Oxygen

Waters in the Tongue and Powder River Basins study region are generally well aerated (Appendix B). The dissolved oxygen minimum established by the U.S. Environmental Protection Agency (1976b) for maintaining healthy fish populations is 5.0 mg/l. Dissolved oxygen levels from 1974 to 1977 at the USGS stations dropped below this level in several creeks of the study area including: Sarpy Creek, (1.8 mg/l minimum value), Salt Creek (0.7 mg/l minimum), Powder River at Arvada (minimum 2.9 mg/l), Mizpah Creek at Olive (0.0 minimum), Powder River near Locate (2.7 minimum), Otter Creek at Ashland (3.0 mg/l minimum), and Pumpkin Creek near Loesch (0.0 minimum). For all of these sampling sites, dissolved oxygen concentrations below the water quality standard were reported in winter months from December to March or April and most likely reflect times of ice cover. The only exceptions to this were a single point in Sarpy Creek (1.8 mg/l in October, also perhaps because of early freezing), and lowered dissolved oxygen concentrations during August in Salt Creek (2.9 mg/l) and Otter Creek (3.0 mg/l). Values below 5.0 mg/l have also been noted at the lower depths of Tongue River Reservoir (U.S. Environmental Protection Agency, 1977c).

pH and Alkalinity

The ionic composition of water and, therefore, biological systems are affected by pH. Waters in the study area are basically alkaline with pH values usually between 7 and 9 (Appendix B). The only exceptions to this range were a few stations in the Rosebud and Tongue River Basins where minimum pH levels occasionally reached 6.7 to 6.9, and in Tongue River Reservoir where maximum pH values collected by the U.S. Environmental Protection Agency (1977c) in August 1975 reached 9.1 at one station and 9.8 at a second sampling site; both of the latter elevated data points were surface water samples.

Alkalinity plays a major role in moderating pH fluctuations. Alkalinity values in the Tongue and Powder River Basin area tend to increase from upstream to downstream (Appendix B) with annual means generally much higher in the Powder Basin than in the Tongue. Alkalinity values were as low as 39 in Greenleaf Creek (Rosebud Creek drainage) and in the 50 to 80 range for a number of smaller tributaries in the study area. Generally, however, waters in this region are well buffered and alkalinity is greater than 100 mg/l for all the basins.

IMPACT OF DEVELOPMENT ON GROUND WATER

Ambient Levels

Ground water in the shallow sandstone and alluvial aquifers along major streams in the Northern Great Plains area is of fair to poor quality because of high concentrations of dissolved solids. The Missouri River Basin Commission (1978a) indicates that mean TDS concentrations of 1,000 to 5,000 mg/l are typical for water from the shallow aquifers and about 1,000 to 2,000 mg/l for water from the Madison and associated aquifers in some parts of the area.

Local ground water variations result from differences in water sources and soil permeability (Northern Great Plains Resource Program, 1974). Water in the more shallow alluvial aquifers responds more rapidly to contamination of surface and near-surface waters than do the deeper bedrock (consolidated materials) aquifers. Water in the deeper aquifers, however, deteriorates with increasing depth as a result of gradual leaching of ions through the formation (Northern Great Plains Resource Program, 1974). Although only limited data are available from wells in the study area and a reliable water quality appraisal of the area is not possible at this time, Tables 46 and 47 show the variability in quality of principal ground-water aquifers in the study area. It appears that the range of TDS values for the shallow aquifers is characteristic of shallow bedrock and alluvial aquifers (Missouri River Basin Commission, 1978a). The chemical quality of water in the deeper Madison aquifer is variable, with TDS levels ranging from about 1,000 mg/l in the Black Hills area in Wyoming and then deteriorating to concentrations as high as 200,000 mg/l towards the center of some geologic basins (Missouri River Basin Commission, 1978a).

Man's Impact

Water quality problems associated with mining include acidity, increased salt content, higher heavy metal concentrations, and greater sediment loads (Warner, 1974). Mines remain pollution sources even after closure, further complicating pollution control.

The current and proposed mining developments in the Powder and Tongue River Basin areas could impact ground water in several ways. The removal of overburden during mining and its replacement for land reclamation expose additional minerals to oxidation and solution with resultant deterioration of ground-water quality (Missouri River Basin Commission, 1978a). One problem is

TABLE 46. RESULTS OF CHEMICAL ANALYSES OF GROUND WATER COLLECTED FROM PRINCIPAL AQUIFERS IN THE NORTHERN POWDER RIVER VALLEY OF MONTANA

		Parameter (mg/1)											
Aquifer Sampled		TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as $CaCO_3$	F
Terrace (alluvial) deposits	*	934	-	6.0	98	55	152	576	302	13	1.7	470	0.4
	*	1710	-	-	89	103	336	578	825	41	11	646	0.8
	AVE	1322	-	6.0	94	79	244	577	564	27	6	558	0.6
Fort Union Formation	*	754	-	25.4	92	127	210	918	413	8	9.3**	754	0.5
Upper Hill Creek Formation	MAX	1290	-	17.4	88	31	408	965	485	40	3.2	347	5.5
	AVE	887	-	2.1	10	4	353	772	108	19	0.5	41	3.1
	MIN	762	-	0.0	0	0	305	613	16	11	0.0	0	1.1
Fox Hills Sandstone and basal Hell Creek Formation	MAX	1170	-	2.1	9	3	442	810	356	43		33	2.5
	AVE	796	-	0.2	2	0.2	326	628	108	23	0.0	6.3	1.5
	MIN	674	-	0.0	0	0	275	506	15	9		0	0.6

*Individual analysis

**Probably contaminated by nearby barnyard

Source: Modified from Northern Great Plains Resource Program (1974).

TABLE 47. RESULTS OF CHEMICAL ANALYSES OF GROUND WATER COLLECTED FROM PRINCIPAL AQUIFERS IN ROSEBUD COUNTY, MONTANA

		Parameter (mg/1)											
Aquifer Sampled		TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_2	SO_4	Cl	NO_3	Hardness as $CaCO_3$	F
Alluvium	MAX	10260	39	8	452	317	2369	1247	3628	492	343	2157	-
	AVE	2230	25	1.7	115	81	508	558	1112	38	21	606	-
	MIN	555	15	-	2.7	2.1	40	122	87	2	-	21	-
Fort Union Formation	MAX	3736	31	19	336	215	571	1427	2440	88	6	1722	-
	AVE	1251	19	1.9	62	52	302	618	458	21	2.1	368	-
	MIN	294	9.6	0.1	4	1.2	16	173	2.6	2	0.0	15	-
Judith River Formation	MAX	4542	16	15	322	281	1220	878	2658	28	20	1650	-
	AVE	1881	13	2.6	122	76	374	416	1015	16	6.9	615	-
	MIN	328	6.4	0.2	27	7	14	154	88	3	-	96	-

Source: Modified from Northern Great Plains Resource Program (1974).

contamination of ground water by infiltration from mining operations. This effect could ultimately impact nearby intermittent streams since water that infiltrates through the spoils materials into shallow aquifers as ground water eventually discharges into streams. The chemical composition of the coal bed, overlying rock strata and surrounding soil types all greatly influence the nature and extent of ground-water contamination (Harza Engineering Company, 1976). The Northern Great Plains Resource Program (1974) reports increases in total dissolved solids, lead, nickel, and zinc concentrations in both ground and surface water samples in the vicinity of Colstrip, Montana, from mining of the Rosebud coal seam. A second problem involves disturbance of saline- and sodium-rich soils in the study area to a sufficient degree that leaching of salts to the ground-water aquifers is substantially increased. Road construction is a secondary impact related to mining activities that has particularly contributed to surface disturbance and resultant salinity problems in the mine-sensitive soils of eastern Montana and Wyoming (Northern Great Plains Resource Program, 1974). Table 48 shows the water quality of two wells from mined and unmined areas in the Rosebud coal bed.

Recently, in situ gasification and liquefaction processes have been tested in the area. Since many of the coal beds are themselves major aquifers, this subsurface disruption could have major impact on ground water. Creation of new fractures will expose unleached areas to ground water (Jones et al., 1977). Introduction of air from above ground will change the water chemistry and solubilities. Finally, the process itself may introduce or release both trace metals and organic contaminants into the ground water (Jones et al., 1977). The nature and extent of this pollution is presently unknown and the subject of intense study.

TABLE 48. WATER QUALITY OF TWO WELLS IN MINED AND UNMINED AREAS

Parameter	Water From Old Spoils and the Rosebud Coal Bed (mg/1)	Water From an Unmined Coal Bed (mg/1)
Calcium	467	53
Magnesium	351	51
Sodium	114	190
Potassium	9.0	8.1
Iron	1.82	0.26
Manganese	1.25	0.07
Bicarbonate	483	553
Carbonate	0	0
Chloride	15.9	4.1
Sulfate	2,418	284
Nitrate	15.5	1.1
Fluoride	0.1	0.1
Total dissolved solids	3,892	1,159

Source: Modified from Harza Engineering Company (1976).

9. ASSESSMENT OF ENERGY RESOURCE DEVELOPMENT

IMPACT ON WATER QUANTITY

The State of Montana has been authorized 60 percent of the annual runoff of the Tongue River Basin and 58 percent of surface water discharges from the Powder River as part of the Yellowstone River Compact. Almost all of the water diverted and consumed in this region is for irrigational use, and although some late season shortages have been reported in Wyoming, generally sufficient surface water is available to meet existing consumptive demands.

There is disagreement between the States of Wyoming and Montana as to the actual quantity of water available for diversion by each State. Surface water supplies in the Tongue and Powder River Basins are highly erratic from season to season and from year to year. The Powder River becomes essentially a dry bed in the late summer months during some years of low rainfall (Northern Great Plains Resource Program, 1974). The Tongue River Dam has tended to normalize the effect of this irregularity in the Tongue River; however, it is presently the only large control structure in the study area, and it cannot completely eliminate the impact of a drought year on regional surface water resources. Energy development, particularly surface mining and the subsequent conversion of coal into electricity, requires enormous amounts of water. Large quantities of water are also needed for reclamation projects to restore mined areas and for planned transportation of coal out of the vicinity in a coal slurry line, the most efficient means of transport. This fact is significant since many of the streams in the coal-rich area of the Tongue and Powder Rivers are dry much of the year. In these basins, ground-water supplies play an important role in supplementing surface flow during the season of low precipitation. However, increased mining activities (which are heavy users of ground water in the Tongue and Powder River drainages) will prevent this source from providing any large-scale cushion to surface water diversions for an extended period of time.

It is sometimes assumed that all water not otherwise consumed is available for diversion and energy utilization. This attitude overlooks the many ecological needs for the "unused" water: instream flow maintenance for the preservation of critical wetlands and riparian habitats, conservation of the native environment of endangered species, etc. The Yellowstone River Compact made no provisions for instream flow maintenance, and theoretically users could continue to divert flow from the Tongue and Powder River Basins until the rivers were dry for many miles. To prevent this possibility, the Yellowstone Moratorium, which suspended all large applications for water right permits in the Yellowstone Basin, was enacted in 1974. The moratorium was designed to allow time for evaluation of all user needs for surface waters in the basin, including agricultural, industrial, and recreational. Until a final decision is made as to which permit applications are to be authorized and how much water can be reliably counted on by each State from year to year for diversion, a firm evaluation of the impact of energy resource development on water quantity in the Powder and Tongue River Basins is not possible. It is clear, however, that the development of additional storage facilities, and perhaps diversion of water from the Yellowstone and Bighorn Rivers through aqueducts, will be necessary in the future to assure that sufficient water will be available to meet anticipated energy development, irrigation, and other demands in the area.

IMPACT ON WATER QUALITY

Surface water quality throughout the Sarpy, Armells, Rosebud, Tongue, and Powder River Basins is highly variable. In intermittent streams of the area, water quality is dependent on seasonal variations in the primary source of flow (whether ground water or precipitation) and the quantity of discharge. In the larger, perennial waters of the Tongue and Powder River Basins, surface quality is somewhat more constant. In the upper portions of the Tongue and Powder Rivers, excellent water can be found, especially at their sources near the Wyoming mountain divides. As the streams progress downstream, however, degradation resulting from hydrologic, geologic, and manmade influences becomes evident. Outstanding cold-water fisheries are replaced by warm-water species or eliminated altogether (Northern Great Plains Resource Program, 1974). In general, water quality is adequate for most irrigation, livestock watering, municipal, and industrial needs of the region. There exist, however, geographically localized problem areas, as well as some specific parameters that are of concern throughout the entire study basin.

At present, salinity levels are the major concern to the basins, particularly in the Powder River where salt concentrations are among the highest in the Northern Great Plains Region. Future energy developments in the basins are expected to impact salt levels primarily through salt-concentrating effects resulting from flow reductions. However, some salt loading to surface and ground waters occurs, and it is currently estimated that wastewater from oil field operations on Salt Creek are responsible for 47 percent of the salinity recorded in the Powder River at Sussex (Missouri River Basin Commission, 1978a).

It is during low flow periods that salt increases can be expected to most severely impact beneficial water uses downstream. Adverse effects of higher salinity include increased costs for municipal and industrial users, lower crop yields, and deterioration of natural habitats. This problem is especially acute in the intermittently flowing river basins where expanded mining activities are expected, such as Rosebud Creek around Colstrip or in the Powder River where severe water quality degradation is already evident.

Sulfate levels, which exceeded the U.S. Environmental Protection Agency (1976b) recommended criteria for drinking water at nearly every station throughout the area, are of particular concern. Although most of the sulfate problem is naturally related to the geologic formations through which the regional water flows, discharges from mining activities are substantially higher in sulfates than the ambient river levels.

Sediment loading is a problem in some parts of the study area, especially in the Powder River, which contributes only 5 percent of the flow of the mainstem Yellowstone River but nearly half of its sediment load (Montana Department of Natural Resources and Conservation, 1977). Increases in sediment problems can be expected as a result of expanding resource development in the area. Mining operations near Sheridan, Wyoming, and in Montana near Decker have already resulted in some localized sediment problems to the Tongue River (Northern Great Plains Resource Program, 1974). Any future industrial and agricultural projects will intensify problems with erosion through construction activities, transport roads, and removal of overburden for mining. As with salinity, the problem of sediment loading to the Tongue and Powder Rivers will be intensified by reduced flows.

Some increases in nutrient and trace element concentrations can also be expected as a result of flow reductions. Population expansion and accompanying construction could further increase nutrient loading to the rivers if not carefully controlled. The effect of the planned energy and irrigation projects on temperature, dissolved oxygen, pH, and alkalinity are not expected to be substantial and will, in all probability, be a result of reduced flows or hydrological modifications produced by supplemental reservoir construction.

The quality of ground water in the basins is fair to poor because of high concentrations of dissolved solids. Much of the low-quality water is natural to the basin, with dissolved solids and the major ions leaching into the ground-water systems from the overlying shale. However, energy developments can intensify the problem. In addition to reducing the ground-water levels to supplement variable surface water flows, contamination of the aquifers is possible. For example, increases in calcium, magnesium, sulfates, and nitrates in ground-water samples in the vicinity of Colstrip, Montana, from mining of the Rosebud coal seam have already been reported (Harza Engineering Company, 1976).

10. RECOMMENDED WATER QUALITY MONITORING PARAMETERS

An objective of water quality monitoring in the Tongue and Powder River Basins should be to assess the impact of energy resource development, irrigation projects, and associated developments. Toward this end a determination of those parameters that would provide meaningful data is needed. The nature and type of possible pollutants from the major activities in the basins were inventoried. The possible effects of these, as well as those parameters that are already being monitored, were reviewed, and a proposed priority list of parameters of interest in the Tongue and Powder River Basins were prepared.

PHYSICAL AND CHEMICAL PARAMETERS

The selection of which water quality parameters should be routinely monitored in the Tongue-Powder study area is not obvious. Physical data provide information on temperature, amount (flow), osmotic pressures (salinity, conductivity), and other factors that affect both the biota and the chemistry. The utility of these data must then be considered when selecting which parameters to measure. Similarly, the ambient level of a chemical and its effect upon the biota and interactions with other chemicals present must be known if a cost-effective monitoring network is to be implemented.

In addition to assessing the quality throughout the water column, the monitoring of substrate composition is also necessary. Many organic and inorganic pollutants are adsorbed onto sediment particles or organic debris. Other pollutants, such as iron, may form flocculants or precipitates or may sink of their own accord. These materials may be deposited in areas of slower moving water or left as evaporites in the dry washes of the area. They may, however, be resuspended during periods of erosion or be released as dissolved parameters following a change in environmental conditions. The deposited sediments therefore represent both a pollutant sink and a potential source. It is necessary to monitor bottom sediment composition in order to obtain a full picture of environmental pollution.

As a means of identifying and setting priorities for those parameters most appropriate for monitoring energy development, each potential pollutant previously addressed is evaluated in terms of the projected impact on ambient water quality with respect to beneficial water use criteria. Also evaluated are those "indicator parameters" that, although not in themselves pollutants, either provide a direct or indirect measurement of environmental disturbances or are required for the interpretation of water quality data. The following symbols are used for identifying those beneficial water uses affected by existing or projected increases in parameter ambient levels:

Symbol		Beneficial Water Uses
I	=	Irrigation
D	=	Drinking water (public water supplies)
A	=	Aquatic life and wildlife
W	=	Industrial uses
L	=	Livestock drinking

Three priority classifications were developed based on criteria given below. These are:

- Priority I (Must Monitor Parameters), which should be collected regularly at energy development assessment monitoring stations.
- Priority II (Major Interest Parameters), which would be desirable to monitor in addition to Priority I parameters if resources permit.
- Priority III (Minor Interest Parameters), which are presently being monitored by the existing network but which will provide little useful data for monitoring energy development impacts on water quality in the Tongue and Powder River Basins.

This classification represents an attempt to (1) identify those parameters that will be effective in monitoring the impact of energy development in the Tongue and Powder River Basins, and (2) permit the detection of increases in parameter levels that may be deleterious to designated beneficial water uses.* This classification scheme is not intended to preclude monitoring of low priority or unmentioned parameters for special studies or for purposes other than assessment of energy development impact. Neither does it require the elimination of those parameters already being collected for baseline data that are very inexpensive to monitor. The priorities do not attempt to address sampling frequency.

Parameters for use in the rapid detection of short duration events such as spills, monitoring for permit discharge purposes, and intensive survey or research projects are not considered in this report. These concerns are important and should not be neglected, but they require considerations that are beyond the scope of this report.

The reasons for monitoring each parameter listed on Tables 49 through 51 are categorized by the following classification scheme:

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*All assessments relative to beneficial water uses are based on U.S. Environmental Protection Agency (1976b) criteria or drinking water regulations (U.S. Environmental Protection Agency, 1975). In those cases where EPA-established criteria have not presently been defined, National Academy of Sciences (1973) recommended criteria are used.

TABLE 49. PRIORITY I, MUST MONITOR PARAMETERS FOR THE ASSESSMENT OF ENERGY DEVELOPMENT IMPACT ON WATER QUALITY IN SARPY, ARMELLS, ROSEBUD, TONGUE, AND POWDER RIVER BASINS

Parameter*	Primary Reason For Monitoring	Category and Beneficial Water Use Code**
Alkalinity, total (as $CaCO_3$)	Needed for interpretation of water quality data	1
Aluminum, total	Periodically exceeded recommended criteria for irrigation and livestock	2I,L
Ammonia, total as N	Periodically exceeded recommended levels for aquatic life, expected to increase	2A;3A
Arsenic, total*	Periodically exceeded recommended criteria for drinking water, irrigation, and livestock in the Powder River; may increase near gasification sites	2D,I,L;3D,I,L
Beryllium, total	Values occasionally reported in excess of aquatic life criterion in Armells Creek and Powder River	2A
Bicarbonate ion	Major anion in the Rosebud and Tongue Rivers; may be affected by energy development	4
Biological oxygen demand of sediments, 5 day*	Measure of pollution increases in the basins; sediment serves as an integrative accumulator	4
Boron, total	Exceeded irrigation criterion in lower Powder River Basin	2I
Cadmium, total	Reported in excess of criteria for drinking water, irrigation, and aquatic life throughout study area; levels may be increased at gasification sites	2A,D,I;3A,D,I
Carbon, total organic in sediments*	Provides indication of organic contamination; many elements and compounds are preferentially absorbed into organic debris	4
Calcium, dissolved	Major cation in upper Tongue and Powder Rivers; may be affected by energy development	4
Chloride	Periodically exceeded EPA criterion for drinking water in Powder River Basin; increased levels anticipated from mine spoil drainage	2D;3D,I
Chromium, total*	Levels reported in excess of drinking water criterion in Armells Creek and Tongue River, and in excess of irrigation and aquatic life criteria as well in the Powder River	2A,D,I
Specific conductance, at 25°C	Useful indicator of TDS; affects overall water chemistry	4

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*Unmarked parameters are determined in water samples only; marked parameters include both water samples and bottom sediments, unless specified for bottom sediments only.

**For full explanation of category codes, see Section 10.

TABLE 49. (Continued)

Parameter*	Primary Reason For Monitoring	Category and Beneficial Water Use Code
Copper, total	Exceeded irrigation water criterion in Armells Creek, and irrigation and livestock criteria in Powder River	2I,L
Cyanide, total*	Reported levels in the early 1970's at Moorhead have exceeded criterion for aquatic life; can be expected to increase as a byproduct of gasification	2A;3A
Dissolved oxygen	Necessary for maintenance of aquatic life and affects water chemistry; at some stations in the study area levels have been less than EPA recommended criterion for aquatic life	1;2A;4
Flow	Needed for interpretation of water quality data	1
Fluoride	Reported in excess of irrigation criterion in the Tongue River below Hanging Woman Creek	2I
Iron, total*	Levels have frequently exceeded recommended criteria for aquatic life, drinking water, and irrigation throughout the study basins; may increase with expanded mining activities	2A,D,I;3A,D,I
Lead, total*	Exceeded drinking water, livestock, and aquatic life standards throughout the study basins, may be increased by gasification plants	2A,D,L;3A,D,L
Magnesium, dissolved	Major cation in upper Rosebud Creek; may be affected by energy development	4
Manganese, total*	Frequently exceeded EPA criteria for drinking water and irrigation; may be increased by gasification	2D,I;3D,I
Mercury, total*	Frequently exceeded EPA criterion for aquatic life and periodically criterion for drinking water; possible contribution from powerplants and gasification plants	2A,D;3A,D
Molybdenum, total	Exceeded irrigation water criterion in lower Powder River Basin	2I
Nickel, total	Periodically exceeded irrigation water criterion in Powder River Basin; could be increased near gasification sites	2I;3I
Pesticides	From available data, no pesticides were reported at levels exceeding criteria for aquatic life. However with increasing agricultural activity, levels of pesticides/herbicides may be expected to increase	3A,D
Petroleum hydrocarbons (includes benzene, toluene, oil and grease, napthalene, phenols, olefins, thiophenes, and cresols)	Can be expected to increase throughout the basin	3A,D

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*Unmarked parameters are determined in water samples only; marked parameters include both water samples and bottom sediments.

TABLE 49. (Continued)

Parameter*	Primary Reason For Monitoring	Category and Beneficial Water Use Code
pH	Needed for interpretation of water quality data	1;4
Phosphorus, total*	Primary nutrient contributing to algal and macrophyte growth; expected to increase	4
Potassium, dissolved	Important cation in study area; may be affected by energy development	4
Selenium, total*	Reported levels exceeded drinking water criterion in Powder River at Arvada, and exceeded irrigation criterion levels as well at South Fork Powder near Kaycee; levels may increase because of stack emissions	2D,I;3D,I
Sodium, dissolved	Dominant cation in lower Rosebud and Powder Rivers; increased levels anticipated from mine spoil drainage and increased use of water conditioners	3D,I;4
Sulfate, dissolved	Dominant anion throughout Powder River and in most other basins during periods of low flow; commonly exceeded EPA criterion for drinking water throughout study area; may be affected by energy development	2D;4
Suspended sediments	Major transport mechanism, indicator parameter, expected to increase with energy development	1;3A,I;4
Temperature	Needed for interpretation of water quality data; could increase with development	1;3A;4
Total dissolved solids	Indicator parameter; downstream salinity problems anticipated with increasing irrigation and energy development, already a problem throughout Powder River Basin	2D,I;3D,I,L,W;4
Zinc, total	Occasionally exceeded irrigation water criterion in Powder River	2I

*Unmarked parameters are determined in water samples only; marked parameters include both water samples and bottom sediments.

TABLE 50. PRIORITY II, PARAMETERS OF MAJOR INTEREST FOR THE ASSESSMENT OF ENERGY DEVELOPMENT IMPACT ON WATER QUALITY IN SARPY, ARMELLS, ROSEBUD, TONGUE, AND POWDER RIVER BASINS

Parameter*	Primary Reason for Monitoring	Category and Beneficial Water Use Code**
BOD, 5 day	May provide basic information on increased pollution	7
COD, low level	May provide an indication of pollution by oxygen consuming substances	7
Total hardness, $CaCO_3$	Of interest to both industry and public; not a problem at present, but may become so as water consumption and irrigation runoff increase	6D,I,W;7
Kjeldahl - N, total	Primary nutrient; expected to increase with development limits in the future	7
Sediment size distribution	Provides data on stream velocity, stream habitat, sediment sources	7
Turbidity	Easy to measure; provides quick data about suspended sediment, etc.	7

*Parameters are determined in water samples only (with the exception of sediment size).
**For full explanation of category codes see Section 10.

TABLE 51. PRIORITY III, PARAMETERS OF MINOR INTEREST THAT WILL PROVIDE LITTLE USEFUL DATA FOR THE ASSESSMENT OF ENERGY DEVELOPMENT IMPACT ON WATER QUALITY IN

Parameter*	Primary Reason For Monitoring	Category and Beneficial Water Use Code**
Antimony, total	Recorded values are very low (maximum 2 μg/l)	8
Barium, dissolved	Difficult to measure, does not approach critical limits (maximum 110 μg/l)	8
Bismuth, dissolved	Recorded values are low (maximum 40 μg/l)	8
Carbonate	Generally low levels in basin; usually of little significance in alkaline waters	8
Cobalt, dissolved	Levels low in basins (maximum 30 μg/l); has few adverse effects at high levels	8
Gallium, dissolved	Values low (maximum 30 μg/l)	8
Germanium, dissolved	Values low (maximum 50 μg/l)	8
Lithium, total	Values range from low to moderately high (maximums 540 μg/l in Powder River at Arvada, and 1200 μg/l in South Fork Powder River near Kaycee), but do not exceed recommended criteria and are not anticipated to increase with development	8
Nitrate-N Nitrate-N	Monitored simultaneously by NO_2-NO_3. If NO_2-NO_3-N levels begin to approach 10,000 μg/l then the NO_2 form would become a "must monitor" priority for health reasons	8
Nitrogen, total	Provides little practical information	8
Phosphorus, dissolved ortho	Total phosphorus considered best measure of potential phosphorus available for biological utilization	8
Sediment minerology	May provide sediment source data	8
Silica	Generally low throughout basins	8
Silver, total	Levels very low (maximum 3 μg/l)	8
Strontium, dissolved	Maximum levels very high in the Armells and Sarpy Creek drainage areas, but has little biological effect	8
Tin, dissolved	Very low levels (maximum 20 μg/l), little adverse effects	8
Titanium, dissolved	Reported values low (maximum 40 μg/l)	8
Vanadium, dissolved	Reported values very low (maximum 17 μg/l)	8
Zirconium, dissolved	Reported values low (maximum 50 μg/l)	8

*Parameters (except for sediment minerology) are determined in water samples only.
**For full explanation of category codes, see Section 10.

Priority I - Must Monitor Parameters

1. Parameters essential for the interpretation of other water quality data. This consideration includes parameters such as temperature, pH, and flow that are necessary to determine loadings, chemical equilibria, biological response, or other factors affecting other parameters.

2. Parameters presently commonly exceeding existing water quality criteria. Consideration is of EPA water quality criteria for beneficial water uses (see codes presented earlier). In cases where EPA-established criteria have not presently been defined, criteria recommended by the National Academy of Sciences (1973) are used.

3. Parameters expected to increase to levels exceeding water quality criteria, unless extreme care is taken. This category includes organic chemical compounds that are expected to be present in future discharges from energy developments and that could reach lethal, mutagenic, or carcinogenic levels unless extreme care is taken. The beneficial use symbols for water quality criteria expected to be exceeded are used here.

4. Parameters that are useful "trace" or "indicator" parameters. These include parameters that, although not causing substantial impact to the aquatic environment themselves, are used to define pollution sources, estimate other parameters of concern, or provide general data on the overall quality of the water. An example would be conductivity, which reflects highly saline springs.

5. Parameters expected to be altered by energy development activities so as to present a threat to a rare or endangered species. This includes a parameter that does not normally affect aquatic life at encountered levels but that, as a result of unique circumstances, may affect a threatened or endangered species. In the Tongue and Powder River Basins, this category situation is not known to exist at present.

Priority II - Major Interest Parameters

6. Potential pollutants of concern. These include parameters whose reported levels in the Tongue and Powder River Basins are presently within acceptable limits for beneficial water uses, but whose ambient levels could be altered by planned regional developments to levels that impair those uses. This differs from category 3 in that, while category 3 parameters are expected to produce problems (either environmental or abatement/disposal), category 6 are those that might be a problem if unrestricted development were permitted.

7. Marginal "trace" or "indicator" parameters. These include parameters that may be used to provide general data on overall quality of the water, to locate pollutant source areas, or to estimate other parameters. Such parameters are not presently routinely monitored or provide little advantage over other measurements being made.

Priority III - Minor Interest Parameters

8. Parameters that are present at very low levels and are unlikely to be significantly changed by planned regional development; are fairly easily monitored but have little effect on beneficial water uses at encountered levels; or provide little useful data for monitoring energy or other development. Many of these parameters are currently being monitored on a regular basis in the Tongue-Powder River study area; however, for purposes of monitoring energy impact development these parameters are not necessary.

Priorities are arranged alphabetically within Tables 49 to 51. The order of their appearance is not intended to suggest a ranking of relative importance.

Although frequency of measurement is not addressed by the priority listings, whenever possible at least monthly collection is recommended for most water quality parameters. Standard analytical techniques should be utilized and the data should be processed and entered into data bases as soon as possible after collection. It should also be stressed that changing conditions within the study area may cause some changes in the priority listings, especially addition of currently unmonitored compounds for which little data are available.

Analysis of bottom sediment samples on an annual or semiannual basis should be performed. Total organic carbon, BOD, grain size, and elemental data should be determined. Sediments from the Tongue River Reservoir should also be sampled and analyzed on a regular basis. Because extensive organic extractions and analyses from sediment samples are expensive, it is not recommended that analysis for specific toxic organic compounds be performed on a routine basis. These analyses should be performed as special studies rather than on a routine monitoring basis at the present time. Bottom sediment parameters of interest are included on Table 49; priority listing of parameters for sediment samples followed the same considerations used in establishing priorities for the water column.

BIOLOGICAL PARAMETERS

The collection of biological data in the Tongue and Powder River Basins would be an effective complementary tool for assessing the impact of energy or irrigation development. Biological investigations are of special significance in water quality monitoring programs because they offer a means of identifying areas affected by pollution and for assessing the degrees of stress from relatively small changes in physical-chemical parameters. Aquatic organisms act as natural monitors of water quality because the composition and structure of plant and animal communities are the result of the biological, chemical, and physical interactions within the system. When only periodic physical-chemical data are collected, an episodic event such as a flash flood or spill may go undetected. The biota affected by an occasional event may require weeks or months to recover. In addition, many biological forms, which accumulate various chemicals preferentially, serve as both an integrative and concentration mechanism that may permit detection of pollutants not detected in the water itself. Finally, because biota are affected by all materials and conditions present in the system, they could be the first indication of a major hazard posed by some unsuspected, unmonitored compound.

Biological monitoring should be initiated in a regular fashion within the Tongue and Powder River system. It should not be viewed as an alternative to other monitoring but as a complementary tool for improving the efficacy of monitoring programs. A comprehensive biological monitoring program is recommended to gather baseline data and permit the eventual refinement of techniques. Such a monitoring effort should be designed to obtain standardized, reproducible data that may be compared from station to station across time. Sampling methods and sites will obviously differ for the different biological communities or parameters. However, for a given community and parameter, sites should be selected that have similar characteristics and the same sampling device and technique used for collection efforts. Replicate samples should be routinely collected and analyzed separately for quality assurance purposes. Of primary interest in biological monitoring is the assessment of changes in community structure over time and space; for such comparisons a minimum of a single year of baseline data is necessary, and the accumulation of several years data is generally required to demonstrate natural temporal variations in the basin's communities.

Taxonomic groups considered appropriate for biological monitoring in the Tongue and Powder River Basins are discussed below:

Macroinvertebrates

These larger forms are relatively easy to collect, quantify, and identify to a meaningful taxonomic level. Being relatively stationary they are unable to escape oncoming waste materials, and their life cycles are sufficiently long to prevent an apparent recovery to periodic relief from pollution. Seasonal sampling (based on stream temperature and flows) should be conducted although annual or semiannual records could be beneficial. Care must be taken to allow sufficient time between sampling of identical areas to permit disturbed populations to reestablish themselves. Macroinvertebrate sampling in lakes should be investigated to determine if sufficient macrobenthos exist to make monitoring them worthwhile.

Periphyton

The periphyton, like the macrobenthos, are unable to escape pollution events. Widespread, rapid-growing, and easy to sample, they are the primary producers in flowing systems and provide basic data on the overall quality of streams and lakes.

Fish

These represent the top of the aquatic food chain and respond to the cumulative effects of stresses on lower forms. In addition, they represent an element of intense public concern. Unlike the previous communities, fish have considerable mobility and may be able to escape localized pollution events. Fish are readily sampled, and taxonomic identification is not difficult in most cases.

Zooplankton

Zooplankton include organisms that graze upon phytoplankton and in turn provide a major food supply for higher forms. The zooplankton can be responsible for unusually low phytoplankton levels as a result of their grazing activities. These forms may provide basic information on environmental regimes and, because of their relatively short life spans and fecundity, may be the first indication of subacute pollution hazards.

Phytoplankton

Present in nearly all natural waters, these plants are easily sampled and can provide basic data on productivity, water quality, potential or occurring problems, etc. Phytoplankton sampling is recommended in lakes and ponds but is not recommended for stream monitoring in these basins.

Microorganisms

Coliform bacteria are generally considered to be indicative of fecal contamination and are one of the most frequently applied indicators of water quality. Criteria exist for bathing and shellfish harvesting waters (U.S. Environmental Protection Agency, 1976b). Other microbiological forms may be useful in the study basins, but these have not been identified and are not discussed.

An annotated list of parameters (Tables 52 through 53) is recommended for monitoring the impact of energy resource development in the Tongue and Powder River Basins. The Priority I category includes those parameters that generally demonstrate an observable response to the type of stress conditions anticipated as a result of increased energy development activities and for which effective monitoring techniques have been developed. It is recommended that Priority I parameters be incorporated into any aquatic biological monitoring program in the basin. The Priority II parameters are those that may be of value to the basins but that are not generally considered to be as likely to provide useful data as those in the Priority I category and should be collected in addition to Priority I parameters only if time and money are available.

It should be noted that the count and biomass determinations in the following discussion are not productivity measurements. Rather they are expressions of standing crops, and although indicative of general productivity, the measurements are really quite different. Productivity data are expressed in units of mass/volume (or area)/unit time.

TABLE 52. PRIORITY I BIOLOGICAL PARAMETERS RECOMMENDED FOR MONITORING WATER QUALITY IN THE TONGUE AND POWDER RIVER BASINS

Taxonomic Group	Parameters	Expressed As	Reason for Sampling
Macroinvertebrates	Counts and identification	Total number/taxon/unit sampling area or unit effort	Provides data on species present, community composition, etc., which may be related to water quality or other environmental considerations.
	Biomass	Weight/unit sampling area or unit effort	Provides data on productivity.
Periphyton	Biomass	Weight/unit substrate	Provides data on productivity.
	Growth rate	Weight/unit substrate/time	Provides data on productivity.
	Identification and estimation of relative abundances*	Taxon present	Indicative of community composition that may be related to water quality rate of recovery from a biological catastrophe, etc.

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*Gross estimates of the quantity or percent of each taxon should be made rather than specific count data/unit area

TABLE 52. (Continued)

Taxonomic Group	Parameters	Expressed As	Reason for Sampling
Fish	Identification and enumeration	Species present*	Provides data on water quality, environmental conditions, and possibly on water uses. Different species respond to different stresses.
	Toxic substances in tissue	Weight/substance/unit tissue weight (by species)	Indication of biological response to toxic pollutants, may provide an "early warning" of pollutants not detected in the water, may pose a health hazard in itself.
Zooplankton	Identification and count	Species present	Provides basic data on environmental conditions.
		Total unit volume or biomass Number/species/unit volume	Provides data on community composition, environmental conditions, and available food size ranges.

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*Count data should be provided for each species

TABLE 52. (Continued)

Taxonomic Group	Parameters	Expressed As	Reason for Sampling
Macrophytes	Species identification and community association	Areal coverage and community	Indication of stream stability, sedimentation, and other factors. Spread of phreatophytes could be a problem in the basin because of their effect on water quality. Initial survey and thereafter occasional examination and stream (lake) side plants is recommended.
Phytoplankton	Chlorophyll a	ug/l	Indication of overall lake productivity - excessive levels often indicate enrichment problems.
	Identification and enumeration	Number/taxon/unit volume Total number/sample (unit volume) or biomass	The presence of specific taxon in abundance is often indicative of water quality and may in themselves pose biological problems.
Microorganisms	Total fecal coliform	Number/unit volume	Indicative of fecal contamination of water supplies and probable presence of other pathogonic organisms.

TABLE 53. PRIORITY II BIOLOGICAL PARAMETERS RECOMMENDED FOR MONITORING WATER QUALITY IN THE TONGUE AND POWDER RIVER BASINS

Taxonomic Group	Parameters	Expressed As	Reason for Sampling
Macroinvertebrates	Toxic substances in tissue	Weight substance/unit tissue weight	Indicative of biological response to toxic pollutants, may provide an "early warning" of pollutants not detected in the water itself.
Periphyton	Chlorophyll a	Unit substrate area	Indicative of productivity of area and general health of the periphyton community.
	Taxonomic Counts	Number/taxon/unit substrate area	Provides additional data on periphyton community composition.
Fish	Biomass	Total weight/sampling effort or unit volume	Indicative of secondary productivity of the water body.
	Flesh tainting	Rating scale (by species)	Indicative of high levels of organic compounds. Likely to be noticed by public. Could indicate pollution from several sources to be due to other causes.

TABLE 53. (Continued)

Taxonomic Group	Parameters	Expressed As	Reason for Sampling
Fish	Size	Length, weight/individual, or range and average size/species	Provides an indication of the age of the community, breeding potential and secondary productivity rates.
	Condition factor	Weight/length (by species)	Indicative of general health of fish community and availability of food.
	Growth rate	Age/length (by species)	Provide data on overall health of the fish community and environmental conditions. Could indicate the presence of subacute pollutants.
Zooplankton	Biomass	Weight/unit volume	Basic data on abundance and overall productivity.
	Eggs, instars, etc.	Species present	Provides basic data on age distribution, presence of seasonal forms, or the existence of cyclic pollution events.
	Toxic substances in tissue	Weight/unit tissue (by species)	May serve as bioconcentrator for specific compounds.

11. ASSESSMENT OF EXISTING MONITORING NETWORK

Estimations can be made regarding the possible impact of proposed developments on water quality, but only after operation can the actual impact be assessed. A well-developed sampling network for the monitoring of environmental parameters is helpful, not only in controlling and assessing pollution from existing projects, but also in providing valuable information for evaluating future projects.

Fifty-three sampling stations in the Sarpy, Armells, Rosebud, Tongue, and Powder River Basins were analyzed to evaluate trends in surface water quality; 45 of these are U.S. Geological Survey sites (Tables 34 through 36) and 8 are operated by the U.S. Forest Service (Tables 35-36). The sampling sites examined were primarily those that had abundant data on which to base analyses of water quality trends. There are a good number of additional USGS and USFS stations located on streams in the study area, but it is felt that the major USGS stations examined in this report are in themselves well situated for future monitoring of surface waters impacted by energy developments. It should be noted that there is no known regional ground-water monitoring network in the study basins. The USGS has for the past several years been conducting periodic sampling of several hundred wells in the region for areal appraisals of the ground-water aquifers but is not monitoring for trends or energy-related changes in the ground-water system (Personal communication, J. Moreland, USGS, Helena, Montana, 1978). The Montana Bureau of Mines and Geology has been handling some site-specific studies at various mines throughout the basins. Although preliminary USGS studies suggest there may be no significant areal impact or change to the ground water from anticipated conventional developments in the study area (Personal communication, J. Moreland, USGS, Helena, Montana, 1978), it is felt that the establishment of a regular ground-water monitoring network, especially one that could measure for potential trace element and organic contamination related to mining activities, would be of great value. Such a program is most needed around underground mine and in situ project sites. At present, prototype in situ conversion procedures are being conducted with which extensive monitoring activities are associated. Time is needed to determine the extent of local contamination resulting from these procedures and those parameters to monitor that would best reflect this contamination.

Good baseline data are available from the USGS stations at Moorhead in the Powder River Basin and at Miles City in the Tongue River Basin, and these locations should continue to be studied for changes in water quality parameters. More intensive sampling of the stations on Sarpy Creek near Hysham, Armells Creek near Forsyth, and Rosebud Creek at the mouth should be attempted since these locations are well situated for observation of water quality degradation because of mining and coal conversion facilities in the study area. Stations in the Yellowstone River at Forsyth, Miles City, and Terry should also be regularly monitored to assess impact of the Tongue and Powder River study region on that river.

Physical and chemical parameters monitored by the sampling network in the Tongue and Powder River Basins and their average annual frequency of measurement are shown in Table 54. This table was constructed from data inventories present in STORET. The average number of times a parameter was sampled each year over the period of record is indicated for each station. Although the completed sampling network in the basins should be adequately located for monitoring the impact of energy development and other activities, there are a few data collection problems with the sampling net that reduce the interpretive utility of the accumulated data. In the past there has been some inconsistency of sampling frequency for many of the parameters. A good number of the parameters recorded in Table 49 as Priority I for monitoring of energy development impact, particularly the trace elements and nutrients, are sampled only intermittently or infrequently. Data for these key parameters are rarely sampled on similar dates across the stations even when they are collected, making spatial or temporal comparisons of the data difficult. A few other Priority I parameters, such as phenols, oils, greases, and pesticides are completely lacking from the existing network or are sampled only rarely. Very little biological data have been gathered by the existing monitoring network in the basins. The problems are aggravated by the unavoidable periodic nature of many of the tributaries flowing through the study area. Nevertheless, available data for salinity-related parameters are generally good, and more complete incorporation of other key parameters into the regular sampling program when streamflow is available would be desirable.

If program restrictions on funding or personnel necessitate, the number of stations regularly sampled in the basins for purposes of monitoring the impact of energy resource development could be substantially reduced. Those USGS stations indicated in Table 55 are recommended as having the highest sampling priority in the Rosebud, Tongue, and Powder River Basins for monitoring the impact of energy development there. Continued sampling of both stations on Armells Creek and the one station at the mouth of the Powder River, to supplement those data available at Moorhead and Locate, is recommended. Of the 21 priority stations throughout the study area, sites in the Tongue River at Miles City, in the Powder River at Moorhead, and in Rosebud Creek at the mouth are the best located for the maintenance of any continuous monitoring activities and should be sampled weekly to allow meaningful trend analyses. Presently, these three important stations are among the most frequently sampled in the USGS network for each of those three basins, particularly for collection of basic monitoring parameters, such as temperature, flow, and salts. However, almost all the elemental parameters considered as having a high monitoring priority (Table 49) are largely neglected, and very few data are available for them at any location throughout the basins.

TABLE 54. PARAMETERS MONITORED BY THE EXISTING SAMPLING NETWORK AT SELECTED STATIONS IN THE TONGUE AND POWDER RIVER BASINS AND THEIR AVERAGE FREQUENCY OF MEASUREMENT

Parameter†				USGS Station Numbers												USFS Stations		
				06295000	06296120	06299980	06295250	06296003	06298000	06307500	06307730	06307740	06307830	06308190	06308400	026301	026501	026503
00010	WATER	TEMP	CENT	13	14	12	11	11	12	11	2	11	13	4	7	--	--	--
00011	WATER	TEMP	FAHN	--	--	--	--	--	--	--	--	--	--	--	--	5	3	4
00041	WEATHER	WMO	CODE	9	19	9	9	9	--	8	--	9	7	*	*	--	--	--
00061	STREAM	INST. FLOW	CFS	13	22	12	11	11	12	11	2	11	13	4	7	6	4	6
00070	TURB	JKSN	JTU	14	27	12	11	11	11	11	2	11	11	4	7	4	2	3
00076	TURB	TRBIDMTR		--	--	--	--	--	--	--	--	--	--	--	--	6	5	5
00094	CNDUCTVY	FIELD	MICROMHO	--	--	--	--	--	--	--	--	--	--	--	--	5	4	4
00095	CNDUCTVY	AT 25C	MICROMHO	13	26	12	11	11	12	11	2	11	13	4	4	9	4	4
00300	DO		MG/L	13	27	10	11	11	11	11	2	11	13	4	7	2	2	2
00310	BOD	5 DAY	MG/L	13	13	12	11	11	12	10	2	11	13	4	7	--	--	--
00400	PH		SU	--	25	12	11	11	12	11	2	11	13	4	7	4	2	4
00403	LAB	PH	SU	--	--	--	--	--	--	--	--	--	--	--	--	4	5	4
00410	T ALK	CACO3	MG/L	13	24	12	11	11	12	11	2	11	12	4	7	4	2	4
00440	HCO3 ION	HCO3	MG/L	13	21	12	11	11	12	11	2	11	11	4	7	4	4	4
00445	CO3 ION	CO3	MG/L	10	19	12	11	11	12	11	2	11	11	4	7	4	4	4
00515	RESIDUE	DISS-105	MG/L	--	--	--	0	1	--	--	2	1	1	--	I	--	--	--
00530	RESIDUE	TOT NFLT	MG/L	--	--	--	0	1	--	--	1	1	1	--	I	--	--	--
00600	TOTAL N		MG/L	10	27	12	11	11	12	11	2	11	13	4	7	--	--	--
00610	NH3-N	TOTAL	MG/L	13	27	12	--	11	12	11	2	11	--	--	7	--	--	--
00625	TOT KJEL	N	MG/L	13	27	12	11	11	12	11	2	11	13	4	7	--	--	--
00630	NO2&NO3	N-TOTAL	MG/L	10	27	12	11	11	12	11	2	11	13	4	7	--	--	--
00631	NO2&NO3	N-DISS	MG/L	4	26	--	--	--	--	--	--	--	I	--	--	7	4	2
00660	ORTHOPO4	PO4	MG/L	5	26	--	--	--	--	--	--	--	--	--	--	7	5	5
00665	PHOS-TOT	P	MG/L	13	27	12	11	11	13	11	2	11	13	4	7	--	--	--
00666	PHOS-DIS	P	MG/L	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
00680	T ORG C	C		4	23	--	--	--	8	--	1	--	--	--	--	--	--	--
00900	TOT HARD	CACO3	MG/L	13	21	12	11	11	12	11	2	11	11	4	7	4	3	4
00902	NC HARD	CACO3	MG/L	13	21	12	11	11	12	11	2	11	11	4	7	--	--	--
00915	CALCIUM	DISS	MG/L	13	21	12	11	11	12	11	2	11	11	4	7	4	4	4
00925	MGNSIUM	DISS	MG/L	13	21	12	11	11	12	11	2	11	11	4	7	4	4	4

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†Parameters are listed by STORET code, name, form, and unit.
*Sampling initiated during the past year; I=intermittently sampled.

TABLE 54. (Continued)

Parameter				USGS Station Numbers												USFS Stations		
				06295000	06296120	06299980	06295250	06296003	06298000	06307500	06307730	06307740	06307830	06308190	06308400	026301	026501	026503
00930	SODIUM	DISS	MG/L	13	21	12	11	11	12	11	2	11	11	4	7	4	4	4
00931	SODIUM	ADSBTION	RATIO	13	21	12	11	11	12	11	2	11	11	4	7	--	--	--
00935	PTSSIUM	K,DISS	MG/L	13	21	12	11	11	12	11	2	11	11	4	7	4	4	4
00940	CHLORIDE	CL	MG/L	13	21	12	11	11	12	11	2	11	11	4	7	4	4	4
00945	SULFATE	SO4-TOT	MG/L	13	21	12	11	11	12	11	2	11	11	4	7	4	3	3
00950	FLORIDE	F,DISS	MG/L	13	21	12	11	11	12	11	2	11	11	4	7	4	4	4
00955	SILICA	DISOLVED	MG/L	13	21	12	11	11	12	11	2	11	11	4	7	5	4	2
01000	ARSENIC	AS,DISS	UG/L	4	4	7	2	2	4	11	1	2	2	4	1	--	--	--
01002	ARSENIC	AS,TOT	UG/L	5	3	10	4	4	4	11	1	6	4	I	5	--	--	--
01005	BARIUM	BA,DISS	UG/L	3	--	1	2	2	--	I	--	2	2	--	I	--	--	--
01010	BERYLIUM	BE,DISS	UG/L	4	4	7	2	2	4	--	1	2	2	I	I	--	--	--
01012	BERYLIUM	BE,TOT	UG/L	5	4	10	4	4	4	4	6	5	3	I	5	--	--	--
01015	BISMUTH	BI,DISS	UG/L	--	--	I	2	2	--	--	2	2	--	--	I	--	--	--
01020	BORON	B,DISS	UG/L	10	11	12	11	11	10	11	10	11	11	4	7	--	--	--
01025	CADMIUM	CD,DISS	UG/L	4	4	3	2	2	4	4	3	2	2	I	1	--	--	--
01027	CADMIUM	CD,TOT	UG/L	5	4	5	4	4	4	4	6	6	4	I	5	--	--	--
01030	CHROMIUM	CR,DISS	UG/L	4	4	3	--	2	4	4	3	2	2	*	1	--	--	--
01034	CHROMIUM	CR,TOT	UG/L	5	4	5	--	4	4	4	6	6	4	I	5	--	--	--
01035	COBALT	CO,TOTAL	UG/L	0	--	I	2	2	--	I	2	2	2	--	I	--	--	--
01040	COPPER	CU,DISS	UG/L	4	4	3	2	2	4	4	3	2	2	I	I	--	--	--
01042	COPPER	CU,TOT	UG/L	5	3	5	4	4	6	4	6	6	4	I	5	--	--	--
01045	IRON	FE,TOT	UG/L	5	1	5	4	4	5	4	6	11	4	I	5	--	--	--
01046	IRON	FE,DISS	UG/L	10	15	12	11	11	4	4	10	6	11	4	7	4	6	4
01049	LEAD	PB,DISS	UG/L	4	4	3	2	2	4	4	2	11	2	I	1	--	--	--
01051	LEAD	PB,TOT	UG/L	5	3	5	4	4	4	4	6	6	4	I	5	--	--	--
01055	MANGNESE	MN	UG/L	5	3	5	4	4	4	4	6	6	3	I	5	--	--	--
01056	MANGNESE	MN,DISS	UG/L	6	18	3	2	2	4	4	2	2	2	I	1	--	--	--
01062	MOLY	TOTAL	UG/L	5	4	5	4	4	4	6	6	6	4	I	5	--	--	--
01065	NICKEL	NI,DISS	UG/L	4	4	3	2	2	4	4	3	2	2	I	1	--	--	--
01067	NICKEL	NI,TOT	UG/L	5	4	5	4	4	4	4	6	6	4	I	5	--	--	--

*Sampling initiated during the past year; I=intermittently sampled.

TABLE 54.1 (Continued)

Parameter				USGS Station Numbers												USFS Stations		
				06295000	06296120	06299980	06295250	06296003	06298000	06307500	06307730	06307740	06307830	06308190	06308400	026301	026501	026503
01075	SILVER	AG,DISS	UG/L	0	--	I	2	2	--	I	2	2	2	--	I	--	--	--
01080	STRONTUM	SR,DISS	UG/L	3	--	I	2	2	--	I	2	2	2	--	I	--	--	--
01085	VANADIUM	V,DISS	UG/L	4	4	3	2	2	4	4	2	2	2	I	1	--	--	--
01090	ZINC	ZN,DISS	UG/L	4	4	3	4	2	4	4	2	2	2	I	1	--	--	--
01092	ZINC	ZN,TOT	UG/L	5	3	4	4	4	3	4	7	7	3	I	5	--	--	--
01100	TIN	SN,DISS	UG/L	--	--	I	--	2	--	I	--	2	2	--	I	--	--	--
01105	ALUMINUM	AL,TOT	UG/L	5	4	4	--	4	3	4	--	I	3	--	1	--	--	--
01106	ALUMINUM	AL,DISS	UG/L	4	4	3	*	2	4	4	1	2	2	I	5	--	--	--
01120	GALLIUM	GA,DISS	UG/L	--	--	I	--	2	--	I	--	2	2	--	I	--	--	--
01125	GERMANUM	GE,DISS	UG/L	--	--	I	--	2	--	I	--	2	2	--	I	--	--	--
01130	LITHIUM	LI,DISS	UG/L	5	4	3	*	2	4	4	--	2	2	I	1	--	--	--
01132	LITHIUM	LI,TOT	UG/L	5	4	5	--	4	4	4	1	6	4	I	5	--	--	--
01145	SELENIUM	SE,DISS	UG/L	4	4	3	*	3	4	4	--	3	3	--	1	--	--	--
01147	SELENIUM	SE,TOT	UG/L	2	3	5	--	4	3	4	1	6	4	--	5	--	--	--
01150	TITANIUM	TI,DISS	UG/L	--	--	I	--	2	--	I	--	2	2	--	I	--	--	--
01160	ZIRCONUM	ZR,DISS	UG/L	--	--	I	--	2	--	I	--	2	2	--	I	--	--	--
31501	TOT COLI	MFIMENDO	/100 ML	--	26	--	--	--	--	--	--	--	--	--	--	1	--	I
31616	FEC COLI	MFM-FCBR	/100 ML	--	31	--	--	--	12	--	--	--	--	--	--	5	5	4
60050	ALGAE	TOTAL		3	12	--	--	--	10	--	--	--	--	--	--	--	--	--
70300	RESIDUE	DISS-180	MG/L	--	15	--	--	--	--	--	--	--	--	--	--	4	5	5
70301	DISS SOL	SUM	MG/L	13	21	12	11	11	12	11	2	11	11	4	7	--	--	--
70302	DISS SOL		TONS/DAY	13	25	12	11	11	11	11	2	11	11	4	7	--	--	--
70303	DISS SOL		PERACRE-FT	13	25	12	11	11	11	11	2	11	11	4	7	--	--	--
71851	NITRATE	DISS-NO3	MG/L	--	--	--	--	--	12	--	--	--	--	--	--	4	5	4
71887	TOTAL N	NO3	MG/L	13	27	12	11	11	12	11	2	11	13	4	7	--	--	--
71890	MERCURY	HG,DISS	UG/L	4	4	3	*	2	4	4	2	2	--	I	1	--	--	--
71900	MERCURY	HG,TOTAL	UG/L	5	3	5	--	4	4	4	2	6	4	I	5	--	--	--
80154	SUSP SED	CONC	MG/L	18	19	16	3	12	--	12	2	12	I	2	10	5	5	5
80155	SUSP SED	DISCHARGE	TONS/DAY	18	19	16	3	12	--	12	2	12	I	2	10	5	5	5

*Sampling initiated during the past year; I=intermittently sampled.

TABLE 55. U.S. GEOLOGICAL SURVEY STATIONS RECOMMENDED TO HAVE THE HIGHEST SAMPLING PRIORITY IN THE TONGUE-POWDER RIVER STUDY AREA FOR MONITORING ENERGY DEVELOPMENT

Station STORET Number	Station Name
06294940	Sarpy Creek near Hysham, MT
06294980	East Fork Armells Creek near Colstrip, MT
06294995	Armells Creek near Forsyth, MT
06295400	Rosebud Creek above Pony Creek, MT
06296003	Rosebud Creek at mouth, near Rosebud, MT
06299980	Tongue River at Monarch, WY
06305500	Goose Creek below Sheridan, WY
06306300	Tongue River at State line near Decker
06307610	Tongue River below Hanging Woman Creek, MT
06308400	Pumpkin Creek near Miles City, MT
06308500	Tongue River at Miles City, MT
06312500	Powder River near Kaycee, WY
06313400	Salt Creek near Sussex, WY
06313500	Powder River at Sussex, WY
06324000	Clear Creek near Arvada, WY
06324500	Powder River at Moorhead, MT
06326300	Mizpah Creek near Mizpah, MT
06326500	Powder River near Locate, MT
06295000	Yellowstone River at Forsyth, MT
06326530	Yellowstone River at Terry, MT
not established	Powder River at mouth, MT

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APPENDIX A

CONVERSION FACTORS

In this report, metric units are frequently abbreviated using the notations shown below. The metric units can be converted to English units by multiplying the factors given in the following list:

Metric Unit to Convert	Multiply by	English Unit to Obtain
Centimeters (cm)	0.3937	Inches
Cubic meters (m^3)	8.107×10^{-4}	Acre-feet
Cubic meters/sec (cms)	35.315	Cubic feet/sec
Hectares (ha)	2.471	Acres
Joules/gram	0.430	Btu/pound
Kilograms (kg)	2.205	Pounds
Kilograms	1.102×10^{-3}	Tons (short)
Kilometers (km)	0.6214	Miles
Liters (1)	6.294×10^{-3}	Barrels (crude oil)
Liters	0.2642	Gallons
Liters/kilogram	239.64	Gallons/ton
Meters (m)	3.281	Feet
Square kilometers (km^2)	247.1	Acres
Square kilometers	0.3861	Square miles

APPENDIX B

CHEMICAL AND PHYSICAL DATA

TABLE B1. DATA SELECTED FROM SELECTED PARAMETERS, 1974-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE ROSEBUD CREEK BASIN

Station*	1974 $\bar{x}$(min-max)n†	1975 $\bar{x}$(min-max)n	1976 $\bar{x}$(min-max)n	1977 $\bar{x}$(min-max)n
Total Dissolved Solids (mg/1)				
9525	821(708-974)3	737(198-1000)12	807(659-943)12	775(555-895)11
9535	--	77(60-94)2	--	--
9540	885(794-1030)3	789(214-1150)12	886(627-1040)12	793(588-981)9
9550	889(782-1030)3	791(215-1100)12	938(749-1190)12	721(353-1030)5
9600	933(832-1040)3	759(220-1210)13	991(754-1270)12	853(437-1250)10
Conductivity (at 25°C, µmho)				
9525	1457(1120-1750)3	1048(310-1700)12	1249(900-1580)12	1193(850-1530)11
9535	--	108(85-130)2	--	--
9540	1460(1280-1600)3	1245(400-1900)12	1338(970-1650)12	1187(900-1550)9
9550	1413(1240-1550)3	1150(350-1870)12	1384(1080-1750)12	1116(540-1720)5
9600	1477(1320-1560)3	1117(330-2060)13	1463(1130-1900)12	1351(1050-1870)10
Dissolved Magnesium (mg/1)				
9525	94(80-110)3	81(19-110)12	90(76-110)12	89(60-110)11
9535	--	4(3-5)2	--	--
9540	103(91-120)3	84(19-110)12	96(78-110)12	88(64-110)9
9550	99(86-110)3	79(18-110)12	100(81-120)12	75(26-110)5
9600	93(85-110)3	74(12-120)13	99(65-130)12	82(34-120)10
Dissolved Sodium (mg/1)				
9525	78(72-87)3	74(29-93)12	77(53-90)12	71(53-89)11
9535	--	2(1-2)2	--	--
9540	80(68-98)3	71(15-120)12	82(47-120)12	72(41-98)9
9550	87(74-110)3	78(21-130)12	95(68-130)12	66(42-97)5
9600	106(88-120)3	86(24-140)13	114(87-190)12	105(60-170)10

*For full description of station locations, see Table 34.
$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates
†the total number os samples collected.

TABLE B1. (Continued)

Station*	1974 $\bar{x}$(min-max)n†	1975 $\bar{x}$(min-max)n	1976 $\bar{x}$(min-max)n	1977 $\bar{x}$(min-max)n
Dissolved Calcium (mg/1)				
9525	78(72-87)3	75(29-93)12	77(53-90)12	71(53-89)11
9535	--	15(13-17)2	--	--
9540	80(72-93)3	75(28-94)12	78(60-92)12	71(56-93)9
9550	76(67-89)3	71(26-98)12	78(61-94)12	70(32-96)5
9600	79(67-87)3	66(25-110)13	78(65-96)12	70(44-97)10
Total Hardness ($CaCO_3$,mg/1)				
9525	580(510-670)3	522(150-670)12	561(480-670)12	547(410-630)11
9535	--	53(44-62)2	--	--
9540	623(550-730)3	532(150-690)12	592(470-680)12	540(430-650)9
9550	597(520-680)3	503(140-700)12	605(490-730)12	486(190-690)5
9600	583(520-670)3	469(110-770)13	603(440-780)12	511(250-700)10
Total Iron (μg/1)				
9525	700(520-880)2	3334(310-7800)5	4835(380-16,000)4	760(-)1
9535	--	2300(-)1	--	--
9540	645(510-780)2	2484(610-5600)5	2815(420-8200)4	1700(-)1
9550	3745(790-6700)2	4138(890-9700)5	3820(680-11,000)4	11,000(-)1
9600	16,950(1900-32,000)2	5700(1200-15,000)6	2150(1000-3400)4	4700(-)1
Total Manganese (μg/1)				
9525	40(30-50)2	200(20-340)5	200(30-600)4	70(-)1
9535	--	70(-)1	--	--
9540	30(30-30)2	124(20-260)5	130(20-310)4	60(-)1
9550	75(40-110)2	134(40-260)5	155(40-420)4	210(-)1
9600	330(90-570)2	157(60-260)6	90(60-130)4	80(-)1

TABLE B1. (Continued)

Station*	1974 $\bar{x}$(min-max)n†	1975 $\bar{x}$(min-max)n	1976 $\bar{x}$(min-max)n	1977 $\bar{x}$(min-max)n
Temperature (°C)				
9525	3.5(0.5-8.0)3	8.1(0-23.0)12	8.6(0-22.5)12	11.0(0-23.0)11
9535	--	0.2(0-0.5)2	--	--
9540	4.2(0.5-9.0)3	8.0(0-23.0)12	8.5(0-22.0)12	12.0(0-23.5)9
9550	4.3(0.5-9.0)3	7.8(0-23.0)12	8.4(0-21.5)12	6.1(0-18.0)5
9600	4.3(0.5-9.0)3	8.0(0-25.0)13	9.1(0-25.0)12	10.6(0-25.0)10
Dissolved Oxygen (mg/l)				
9525	11.3(9.6-12.4)3	9.5(6.2-12.6)12	10.2(6.6-12.4)11	9.7(7.3-13.8)11
9535	--	10.7(10.6-10.8)2	--	--
9540	11.2(9.4-12.3)3	9.4(6.5-12.2)12	10.3(6.8-13.8)11	9.0(7.3-11.5)9
9550	11.2(9.0-12.7)3	9.7(5.9-12.2)12	10.2(7.0-12.6)12	9.6(7.5-11.5)5
9600	11.3(9.2-13.0)3	10.2(6.2-12.8)13	10.8(8.3-13.2)12	10.0(7.5-13.0)10
Dissolved Potassium (mg/l)				
9525	10.8(9.4-12.0)3	9.2(7.4-11.0)12	9.5(8.2-11.0)12	9.3(7.1-12.0)11
9535	--	6.6(5.6-7.5)2	--	--
9540	11.3(11.0-12.0)3	9.1(1.1-12.0)12	9.8(7.8-12.0)12	9.4(7.2-13.0)9
9550	10.9(9.7-12.0)3	9.5(7.3-12.0)12	9.9(8.3-12.0)12	8.6(7.7-10.0)5
9600	10.2(9.6-11.0)3	9.3(5.0-12.0)13	10.3(8.3-13.0)12	9.5(7.4-12.0)10
Bicarbonate (mg/l)				
9525	524(482-606)3	462(132-594)12	476(281-576)12	471(370-560)11
9535	--	58(48-67)2	--	--
9540	501(422-603)3	454(140-617)12	492(392-587)12	446(390-564)9
9550	512(460-580)3	424(139-616)12	472(427-611)12	409(150-586)5
9600	501(469-563)3	398(133-636)13	495(399-624)12	432(209-610)10

TABLE B1. (Continued)

Station*	1974 $\bar{x}$(min-max)n†	1975 $\bar{x}$(min-max)n	1976 $\bar{x}$(min-max)n	1977 $\bar{x}$(min-max)n
Total Sulfate (mg/l)				
9525	283(230-350)3	260(54-420)12	300(220-380)12	285(190-350)11
9535	--	12.6(6.3-19.0)2	--	--
9540	330(290-390)3	302(62-560)12	352(220-430)12	312(200-420)9
9550	343(300-400)3	318(139-616)12	472(427-611)12	409(150-586)5
9600	377(330-410)3	304(68-530)13	422(310-620)12	352(140-600)10
Chloride (mg/l)				
9525	5.1(4.8-5.2)3	4.9(1.1-7.0)12	5.0(3.4-6.5)12	5.0(3.0-6.9)11
9535	--	1.6(1.3-2.0)2	--	--
9540	5.3(4.9-5.5)3	5.0(3.1-6.4)12	6.0(4.0-13.0)12	4.8(3.3-6.2)9
9550	5.0(4.3-5.5)3	5.4(2.7-7.3)12	5.6(3.9-7.5)12	4.7(3.5-6.4)5
9660	5.8(5.1-6.3)3	5.0(2.8-7.6)13	5.7(2.2-7.1)12	5.6(3.3-9.2)10
Dissolved Silica (mg/l)				
9525	18(17-19)3	15(7-21)12	15(11-20)12	15(9-22)11
9535	--	7(6-8)2	--	--
9540	17(16-19)3	15(8-22)12	15(10-19)12	14(7-22)9
9550	15(14-18)3	15(8-21)12	14(9-20)12	14(7-22)5
9600	14(10-17)3	13(8-21)13	14(8-19)12	12(7-22)10
pH (SU)				
9525	8.2(8.0-8.6)3	8.2(7.5-8.9)12	8.3(7.9-8.5)12	8.3(8.0-8.6)11
9535	--	7.7(7.4-8.0)2	--	--
9540	8.4(8.0-8.8)3	8.2(7.5-8.5)12	8.2(7.4-8.7)12	8.3(7.9-8.6)9
9550	8.2(8.0-8.3)3	8.1(7.5-8.5)12	8.2(7.8-8.6)12	8.3(7.9-8.5)5
9600	8.3(8.0-8.5)3	8.1(7.5-8.5)13	8.1(6.9-8.8)12	8.3(7.4-8.7)10

TABLE B1. (Continued)

Station*	1974 $\bar{x}$(min-max)n†	1975 $\bar{x}$(min-max)n	1976 $\bar{x}$(min-max)n	1977 $\bar{x}$(min-max)n
Total Alkalinity ($CaCO_3$, mg/1)				
9525	436(395-497)3	381(108-487)12	400(287-472)12	389(310-460)11
9535	--	47(39-55)2	--	--
9540	432(391-495)3	378(115-506)12	408(322-481)12	367(320-463)9
9550	420(377-476)3	354(114-505)12	396(350-501)12	336(123-481)5
9600	411(385-462)3	335(109-522)13	411(327-512)12	358(170-500)10

TABLE B2. FLOW (m^3/sec), 1973-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max)n†	$\bar{x}$ (min-max)n	$\bar{x}$ (min-max)n	$\bar{x}$ (min-max)n	$\bar{x}$ (min-max)n	$\bar{x}$ (min-max)n
9800	2.2(1.8-2.5)4	4.9(1.4-31.7)14	9.5(1.2-41.3)12	4.1(1.4-15.9)12	4.9(1.4-21.4)12	1.6(1.4-1.7)3
9998	--	9.0(2.5-42.8)9	12.5(1.9-50.9)12	5.4(1.8-29.7)13	6.0(1.4-26.6)12	2.2(1.5-2.5)3
0550	3.8(1.7-5.7)6	3.6(0.9-13.9)17	9.1(1.3-41.9)21	5.0(1.3-23.9)27	3.7(1.4-13.2)15	1.9(-)1
0610	--	--	0.04(0.03-0.05)3	0.1(0.01-0.3)12	0.2(0.01-1.4)11	0.1(0.01-1.4)26
0630	10.7(10.0-11.4)4	11.8(3.4-48.4)13	26.9(5.1-96.3)12	10.2(3.4-33.7)13	11.1(2.0-41.9)13	14.5(2.0-96.3)55
0680	--	--	0.01(0.002-0.3)7	0.01(0.1-0.01)2	0.01(-)1	0.1(0.002-0.3)10
0750	--	--	4.0(0.7-6.1)3	12.9(3.8-42.8)12	12.1(0.1-66.3)12	11.4(0.1-66.3)27
0760	--	0.03(0.02-0.03)3	0.9(0.05-3.5)15	0.1(0.02-0.4)12	0.05(0.02-0.3)11	0.4(0.02-3.5)41
0761	--	14.3(6.3-43.3)9	22.3(1.3-99.1)12	12.8(3.8-43.0)12	12.3(2.7-66.6)12	4.2(-)2
0767	--	--	0.5(0.01-1.5)4	0(-)1	0.4(0-1.5)5	--
0774	--	0.1(0.01-0.1)3	1.0(0.02-8.1)13	0.1(0-0.3)12	0.1(0.002-0.2)11	0.4(0.002-8.1)39
0781	--	--	0.6(0.03-1.2)5	0.02(0.02-0.03)4	0.4(0.02-1.2)9	--
0783	--	13.3(5.7-41.3)9	25.3(2.4-99.1)14	11.9(4.7-32.0)12	15.2(4.7-60.9)11	17.1(2.4-99.1)46
0784	--	--	0.4(0.3-0.5)2	0.01(-)1	--	0.3(0.01-0.5)4
0816	--	--	0.01(-)1	0.01(0-0.01)7	0.001(0-0.03)5	0.01(0-0.03)13
0817	--	--	--	0.01(0.001-0.01)3	0.01(0-0.03)3	0.01(0-0.03)6
0819	--	--	0.003(-)1	0.1(0-0.1)5	0.04(0.01-0.1)3	0.05(0-0.1)9
0840	--	--	0.01(0.001-0.02)3	1.2(0.01-7.2)7	0.6(0-1.4)5	0.7(0-7.2)15
0850	11.1(5.3-15.3)3	11.8(4.0-37.1)13	23.2(2.5-117.2)13	12.8(4.2-43.3)12	9.5(2.8-38.2)13	4.2(3.9-4.6)2

*For full description of station locations, see Table 35.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B3. TOTAL DISSOLVED SOLIDS (mg/1), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
9800	138(94-164)14	134(86-154)13	131(72-168)12	130(81-150)13	133(66-153)11	134(83-170)12	138(95-182)12	137(83-167)8
9998	--	--	--	--	272(93-524)9	285(106-376)12	269(149-395)13	263(128-347)10
0550	440(101-626)10	399(111-620)12	371(94-481)12	423(113-564)14	401(149-622)12	412(95-600)12	409(124-600)13	411(132-575)10
0610	--	--	--	--	--	844(826-866)3	727(605-938)12	721(377-956)10
0630	448(145-657)28	498(153-732)12	459(193-623)12	439(160-624)11	520(157-710)11	416(130-570)12	453(152-626)13	438(174-571)9
0680	--	--	--	--	--	2765(268-4950)7	4050(3560-4540)2	4680(-)1
0750	--	--	--	--	--	534(523-540)3	432(195-617)12	429(247-522)9
0760	--	--	--	--	1670(1620-1740)3	1634(176-2630)14	1535(896-2020)11	1763(1200-2090)10
0761	--	--	--	--	402(193-581)8	468(176-896)11	461(202-687)11	449(245-564)11
07615	--	--	--	--	1380(1310-1470)3	1070(152-1410)10	1223(1150-1310)11	1241(1140-1320)9
0767	--	--	--	--	--	798(140-2330)4	646(-)1	--
0774	--	--	--	--	2223(2080-2320)3	1840(228-2690)13	2069(1610-2590)12	2150(1620-2460)10
0781	--	--	--	--	--	1373(230-2970)5	3122(2920-3400)4	--
0783	--	--	--	--	540(473-620)3	520(203-868)12	506(217-657)12	473(267-661)9
0784	--	--	--	--	--	94(84-103)2	--	193(-)1
0816	--	--	--	--	--	3720(-)1	4200(3290-5160)7	4714(3340-6430)5
0817	--	--	--	--	--	--	2887(2700-3090)3	2507(1360-3760)3
0819	--	--	--	--	--	5950(-)1	3754(2980-4580)5	3510(2750-4710)3
0840	--	--	--	--	--	2473(2220-2840)3	1319(120-3190)7	810(303-1580)4
0850	555(322-789)12	560(295-756)11	568(291-792)12	549(262-761)12	550(215-843)13	578(290-912)13	559(281-717)12	495(234-665)9

*For full description of station locations, see Table 35.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B4. CONDUCTIVITY (µmho/cm at 25°C), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
9800	245(166-289)14	235(149-271)13	237(129-297)12	237(145-272)13	233(121-294)13	242(130-340)12	270(165-360)12	220(50-280)9
9998	--	--	--	--	405(170-550)9	420(200-540)12	448(225-640)13	428(190-570)13
0550	690(174-962)10	620(163-933)12	598(163-768)12	678(182-869)14	623(228-980)13	677(195-1010)12	660(215-900)13	678(210-860)13
0610	--	--	--	--	--	1280(1240-1340)3	1148(915-1550)12	1120(630-1710)10
0630	690(247-987)28	747(252-1070)12	711(322-914)12	673(262-939)12	735(282-989)12	650(230-970)12	698(260-910)13	731(300-930)13
0680	--	--	--	--	--	3599(450-6250)7	4700(4200-5200)2	5810(-)1
0750	--	--	--	--	--	830(800-850)3	698(330-945)12	685(421-928)11
0760	--	--	--	--	2472(2325-2630)3	2258(240-3700)14	2198(1220-2800)12	2484(1720-2810)10
0761	--	--	--	--	660(330-890)9	734(280-1310)12	747(343-1040)12	723(428-990)11
07615	--	--	--	--	2140(2070-2250)3	1536(270-2030)10	1813(1590-2170)12	1818(1710-2060)9
0767	--	--	--	--	--	1095(225-3000)4	970(-)1	--
0774	--	--	--	--	3370(2980-3900)3	2482(370-3500)13	2772(2300-3260)12	2903(2320-3180)10
0781	--	--	--	--	--	1844(400-3800)5	3960(3730-4080)4	--
0783	--	--	--	--	808(360-1120)9	802(350-1300)13	786(361-1040)12	723(434-1050)10
0784	--	--	--	--	--	128(120-135)2	--	170(-)1
0816	--	--	--	--	--	4830(-)1	5041(4100-5900)7	6630(4200-10,000)5
0817	--	--	--	--	--	--	3587(3410-3720)3	4293(1830-7850)3
0819	--	--	--	--	--	7000(-)1	4706(3880-5400)5	4907(4200-5900)3
0840	--	--	--	--	--	3620(3160-3850)3	1821(195-4120)7	1392(460-2400)4
0850	838(503-1150)12	844(467-1140)12	854(463-1120)12	849(445-1170)12	878(365-1230)13	848(440-1320)13	815(440-1040)12	786(390-975)11

*For full description of station locations, see Table 35.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B5. DISSOLVED CALCIUM (mg/1), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
9800	36(25-44)14	33(22-38)13	33(18-39)12	33(23-40)13	31(12-37)11	35(21-56)12	33(22-45)12	33(18-44)8
9998	--	--	--	--	47(21-57)9	45(25-58)12	49(28-67)13	47(25-57)10
0550	60(18-82)10	58(17-84)12	54(14-66)12	62(22-78)14	58(33-85)12	60(16-79)12	58(18-87)13	56(23-69)10
0610	--	--	--	--	--	93(89-100)3	82(67-99)12	80(59-100)10
0630	58(27-78)28	68(26-91)12	65(31-79)12	66(30-83)11	72(30-110)11	60(24-79)12	66(26-84)13	61(27-75)9
0680	--	--	--	--	--	192(32-320)7	275(260-290)2	300(-)1
0750	--	--	--	--	--	73(67-78)3	60(29-81)12	58(39-74)11
0760	--	--	--	--	100(100-100)3	98(27-150)14	94(54-120)11	102(88-120)10
0761	--	--	--	--	56(31-83)8	58(30-81)11	59(30-86)11	57(38-74)11
07615	--	--	--	--	92(89-97)3	73(19-94)10	80(71-88)11	78(72-82)9
0767	--	--	--	--	--	60(21-160)4	39(-)1	--
0774	--	--	--	--	85(67-110)3	77(23-120)13	82(45-120)12	77(52-120)10
0781	--	--	--	--	--	83(20-170)5	152(140-160)4	--
0783	--	--	--	--	68(57-80)3	60(27-88)12	61(32-77)12	56(38-75)10
0784	--	--	--	--	--	18(17-19)2	--	13(-)1
0816	--	--	--	--	--	230(-)1	210(170-260)7	236(180-310)5
0817	--	--	--	--	--	--	133(130-140)3	121(74-180)3
0819	--	--	--	--	--	230(-)1	142(90-170)5	147(130-180)3
0840	--	--	--	--	--	71(59-90)3	52(9-100)7	31(12-65)4
0850	64(45-85)12	63(35-91)11	63(31-86)12	62(36-85)12	63(33-95)13	61(27-83)13	61(40-80)12	58(35-77)10

*For full description of station locations, see Table 35.
†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B6. DISSOLVED SODIUM (mg/1), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
9800	2(1-2)14	2(1-8)13	2(1-5)12	1(1-2)13	2(1-3)11	1(1-2)12	2(2-4)12	2(1-4)7
9998	--	--	--	--	17(3-46)9	16(3-31)12	16(6-25)13	15(5-27)10
0550	29(5-47)10	25(6-43)12	23(6-33)12	26(6-42)14	26(10-41)12	26(5-41)12	27(7-39)13	29(6-49)10
0610	--	--	--	--	--	45(44-46)3	38(22-65)12	39(13-59)10
0630	33(8-63)28	37(9-61)12	31(13-46)12	30(8-49)11	36(8-53)11	28(6-40)12	32(8-45)13	32(9-48)9
0680	--	--	--	--	--	437(30-720)7	630(540-720)2	800(-)1
0750	--	--	--	--	--	39(37-40)3	30(13-46)12	31(16-44)11
0760	--	--	--	--	300(290-310)3	283(17-490)14	267(150-360)11	317(210-380)10
0761	--	--	--	--	32(13-48)8	42(14-110)11	39(14-60)11	37(16-52)11
07615	--	--	--	--	197(190-200)3	150(16-200)10	177(140-210)11	187(170-210)9
0767	--	--	--	--	--	125(14-390)4	120(-)1	--
0774	--	--	--	--	417(390-440)3	314(26-460)13	317(290-470)12	401(310-460)10
0781	--	--	--	--	--	226(30-490)5	492(390-560)4	--
0783	--	--	--	--	50(44-56)3	53(19-110)12	48(17-68)12	42(18-76)10
0784	--	--	--	--	--	4(4-5)2	--	37(-)1
0816	--	--	--	--	--	630(-)1	727(550-960)7	806(570-1100)5
0817	--	--	--	--	--	--	447(400-500)3	373(190-560)3
0819	--	--	--	--	--	1300(-)1	732(540-880)5	677(520-900)3
0840	--	--	--	--	--	670(610-790)3	319(26-830)7	206(70-400)4
0850	61(25-87)12	66(33-94)12	66(30-110)12	62(26-100)12	58(17-92)13	72(29-130)13	65(37-110)12	54(18-82)10

*For full description of station locations, see Table 35.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B7. DISSOLVED MAGNESIUM (mg/1), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
9800	10(6-16)14	10(6-13)13	10(4-14)12	10(4-13)13	12(1-29)11	10(3-16)12	12(7-16)12	11(6-14)8
9998	--	--	--	--	24(6-48)9	21(8-31)12	22(12-32)13	22(10-28)10
0550	43(8-62)10	38(8-57)12	35(7-46)12	40(6-53)14	38(4-65)12	38(7-59)12	39(11-56)13	40(10-58)10
0610	--	--	--	--	--	99(98-100)3	87(66-110)12	89(41-120)10
0630	40(10-60)28	43(12-68)12	41(13-57)12	37(11-52)11	48(1-77)11	36(10-52)12	40(12-56)13	40(17-51)9
0680	--	--	--	--	--	175(14-340)7	260(230-290)2	310(-)1
0750	--	--	--	--	--	48(47-50)3	39(16-58)12	39(21-49)11
0760	--	--	--	--	117(110-130)3	106(11-170)14	105(52-130)12	117(72-130)10
0761	--	--	--	--	37(16-50)9	41(13-73)12	42(17-61)12	40(21-51)11
07615	--	--	--	--	130(130-130)3	92(11-120)10	108(100-120)12	111(100-120)9
0767	--	--	--	--	--	52(9-150)4	38(-)1	--
0774	--	--	--	--	170(150-180)3	137(15-190)13	157(130-200)12	161(120-190)10
0781	--	--	--	--	--	100(15-220)5	235(220-260)4	--
0783	--	--	--	--	47(41-55)3	41(15-62)12	43(17-57)12	39(20-55)10
0784	--	--	--	--	--	5(4-6)2	--	7(-)1
0816	--	--	--	--	--	250(-)1	271(210-340)7	298(200-380)5
0817	--	--	--	--	--	--	230(220-250)3	197(110-290)3
0819	--	--	--	--	--	280(-)1	210(170-250)5	187(140-260)3
0840	--	--	--	--	--	59(50-68)3	42(4-89)7	21(4-47)4
0850	43(23-70)12	41(20-57)11	43(17-64)12	43(20-62)12	44(16-69)13	44(14-61)13	43(17-58)12	42(20-55)10

*For full description of station locations, see Table 35.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B8. DISSOLVED POTASSIUM (mg/1), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
980C	0.9(0.4-1.7)14	0.8(0-1.6)13	0.8(0.2-2.2)12	0.7(0.5-0.9)13	0.8(0.5-1.4)11	0.9(0.5-1.4)12	0.9(0.2-1.6)12	0.8(0.5-1.4)8
9998	--	--	--	--	2.0(0.9-4.4)9	2.5(0.9-7.4)12	1.9(1.2-2.7)13	1.8(1.0-2.5)10
0550	3.2(0.9-5.5)10	3.0(0.7-4.7)12	2.7(0.9-5.1)12	2.8(0.9-4.7)14	2.9(1.2-4.9)12	3.5(1.4-9.1)12	2.6(1.4-4.0)13	3.0(0.7-4.5)10
0610	--	--	--	--	--	8.4(7.1-10)3	7.1(5.1-11.0)12	6.6(4.6-8.5)10
0630	3.4(1.3-6.5)28	4.1(1.8-7.4)12	3.1(1.9-4.2)12	3.2(1.4-4.9)11	3.5(1.4-4.4)11	3.6(1.4-6.3)12	3.2(1.6-4.9)13	3.1(1.4-4.9)9
0680	--	--	--	--	--	11.8(7.9-17.0)7	16.0(15.0-17.0)2	15(-)1
0750	--	--	--	--	--	4.3(3.9-4.7)3	3.5(1.7-4.9)12	3.6(2.3-5.3)11
0760	--	--	--	--	13.7(13.0-15.0)3	13.7(7.6-16.0)14	13.7(12.0-16.0)11	13.8(7.5-17.0)10
0761	--	--	--	--	3.6(1.8-4.6)8	4.9(1.7-7.3)11	3.8(1.8-5.1)11	3.8(2.6-4.7)11
07615	--	--	--	--	13.7(13.0-15.0)3	12.4(6.6-15.0)10	13.5(12.0-16.0)11	12.8(11.0-14.0)9
0767	--	--	--	--	--	11.0(5.8-18.0)4	11.0(-)1	--
0774	--	--	--	--	23.0(18.0-27.0)3	16.6(8.1-24.0)13	19.7(16.0-22.0)12	20.8(15.0-37.0)10
0781	--	--	--	--	--	14.0(9.4-20.0)5	22.0(19.0-25.0)4	--
0783	--	--	--	--	4.5(4.3-4.6)3	5.2(2.1-8.3)12	4.2(2.0-5.2)12	4.0(2.8-5.2)10
0784	--	--	--	--	--	5.6(5.4-5.9)2	--	8.2(-)1
0816	--	--	--	--	--	22.0(-)1	21.4(17.0-26.0)7	20.6(17.0-24.0)5
0817	--	--	--	--	--	--	25.7(22.0-30.0)3	16.7(2.1-29.0)3
0819	--	--	--	--	--	21(-)1	17.2(15.0-20.0)5	17.7(13.0-21.0)3
0840	--	--	--	--	--	12.0(11.0-13.0)3	9.1(4.6-15.0)7	6.5(3.2-12.0)4
0850	5.2(3.3-6.6)12	5.3(3.0-8.2)11	5.2(3.2-8.4)12	5.0(2.8-8.7)12	4.6(1.9-6.1)13	5.1(3.2-6.7)13	4.6(2.9-5.3)12	4.6(2.8-5.6)10

*For full description of station locations, see Table 35.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B9. BICARBONATE ION (mg/1), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
9800	149(98-177)14	144(92-171)13	141(75-170)12	139(85-164)13	146(70-167)11	149(90-200)12	154(100-210)12	151(86-180)8
9998	--	--	--	--	198(85-258)9	199(101-250)12	218(125-298)13	214(110-260)10
0550	264(74-326)10	240(90-319)12	230(65-293)12	265(73-322)14	260(92-330)12	266(65-360)12	264(85-360)13	270(79-340)10
0610	--	--	--	--	--	541(527-557)3	445(371-585)12	444(240-608)10
0630	213(110-316)28	253(102-331)12	253(114-304)12	244(107-306)11	286(113-330)11	246(100-320)12	263(110-340)13	266(130-340)9
0680	--	--	--	--	--	406(86-638)7	600(577-623)2	660(-)1
0750	--	--	--	--	--	286(274-300)3	245(131-332)12	239(150-314)10
0760	--	--	--	--	644(631-669)3	480(89-669)14	558(251-648)12	602(340-660)10
0761	--	--	--	--	227(131-285)9	246(122-376)11	256(124-357)12	244(150-316)11
07615	--	--	--	--	650(636-660)3	522(92-670)10	649(542-709)12	661(614-720)9
0767	--	--	--	--	--	225(69-584)4	233(-)1	--
0774	--	--	--	--	690(657-749)3	532(110-810)13	621(454-754)12	660(550-789)10
0781	--	--	--	--	--	374(94-747)5	704(650-755)4	--
0783	--	--	--	--	282(256-334)4	258(124-397)12	265(135-338)12	252(150-340)10
0784	--	--	--	--	--	64(60-69)2	--	55(-)1
0816	--	--	--	--	--	716(-)1	720(597-959)7	759(510-1110)5
0817	--	--	--	--	--	--	668(624-732)3	468(239-746)3
0919	--	--	--	--	--	961(-)1	586(464-702)5	528(433-670)3
0840	--	--	--	--	--	539(411-672)3	362(67-876)7	238(140-390)4
0850	285(196-389)12	269(152-369)11	272(139-388)12	285(157-396)12	284(139-448)13	275(142-373)13	280(174-360)12	252(150-343)9

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*For full description of station locations, see Table 35.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B10. SULFATE (mg/1), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
9800	5(2-11)14	6(2-15)13	7(2-18)12	6(2-9)13	6(2-8)11	4(1-8)12	6(0-19)12	5(1-9)8
9998	--	--	--	--	75(11-240)9	66(12-120)12	64(24-110)13	63(22-110)10
0550	155(25-250)10	142(22-260)12	124(25-190)12	143(27-240)14	132(40-260)12	138(22-230)12	134(35-210)13	133(40-220)10
0610	--	--	--	--	--	313(300-320)3	275(220-350)12	270(130-350)10
0630	188(35-323)28	208(47-340)12	179(67-280)12	166(44-270)11	204(39-300)11	154(30-240)12	169(40-250)13	156(45-240)9
0680	--	--	--	--	--	1728(130-3200)7	2550(2200-2900)2	2900(-)1
0750	--	--	--	--	--	220(220-220)3	169(61-260)12	169(84-210)10
0760	--	--	--	--	790(760-820)3	872(57-1500)14	753(420-1100)12	888(630-1100)10
0761	--	--	--	--	155(59-260)8	190(47-420)11	190(71-280)12	181(86-230)11
07615	--	--	--	--	593(520-670)3	460(46-660)10	490(430-520)12	491(460-520)9
0767	--	--	--	--	--	424(47-1300)4	310(-)1	--
0774	--	--	--	--	1167(1100-1200)3	1006(80-1500)13	1100(850-1400)12	1134(740-1300)10
0781	--	--	--	--	--	748(100-1700)5	1850(1700-2000)4	--
0783	--	--	--	--	217(190-250)	220(63-390)12	211(74-280)12	191(97-290)9
0784	--	--	--	--	--	21(15-27)2	--	59(-)1
0816	--	--	--	--	--	2200(-)1	2586(2000-3100)7	2940(2100-4000)5
0817	--	--	--	--	--	--	1700(1600-1800)3	1543(830-2300)3
0819	--	--	--	--	--	3600(-)1	2340(1800-3100)5	2200(1700-3000)3
0840	--	--	--	--	--	1367(1200-1500)3	704(38-1700)7	412(120-830)4
0850	229(114-337)12	241(110-360)11	244(120-370)12	225(89-340)12	228(68-350)13	249(98-440)13	237(89-310)12	209(76-290)10

*For full description of station locations, see Table 35.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B11. CHLORIDE (mg/1), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max)n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
9800	3(0-9)14	1(0-3)13	2(0-4)12	2(0-3)13	2(0-7)11	2(0-5)12	1(0-2)12	3(0-10)8
9998	--	--	--	--	2(1-4)9	2(1-5)12	2(1-4)13	2(1-3)10
0550	7(1-16)10	4(1-7)12	5(1-12)12	5(2-9)14	4(2-7)12	6(2-11)12	4(2-11)13	7(2-18)10
0610	--	--	--	--	--	4(3-6)3	4(2-7)12	3(2-8)10
0630	5(1-11)28	4(1-7)12	4(2-6)12	4(2-8)11	8(0-57)11	4(2-11)12	4(2-6)13	6(2-18)9
0680	--	--	--	--	--	13(4-27)7	16(16-17)2	19(-)1
0750	--	--	--	--	--	4(3-4)3	3(1-5)12	3(1-4)10
0760	--	--	--	--	11(11-12)3	11(4-14)14	10(2-13)12	12(3-17)10
0761	--	--	--	--	3(1-4)8	4(2-6)11	4(1-7)12	3(1-4)11
07615	--	--	--	--	7(7-8)3	6(2-10)10	7(3-11)12	6(4-7)9
0767	--	--	--	--	--	6(3-13)4	4(-)1	--
0774	--	--	--	--	14(12-16)3	11(3-16)13	11(1-16)12	15(2-29)10
0781	--	--	--	--	--	6(3-11)5	8(1-11)4	--
0783	--	--	--	--	4(3-5)3	4(1-6)12	4(2-6)12	4(2-5)9
0784	--	--	--	--	--	2(2-2)2	--	37(-)1
0816	--	--	--	--	--	17(-)1	14(12-18)7	19(14-26)5
0817	--	--	--	--	--	--	11(10-12)3	10(8-13)3
0819	--	--	--	--	--	26(-)1	16(12-23)5	15(13-17)3
0840	--	--	--	--	--	10(10-11)3	6(2-13)7	5(2-8)4
0850	4(1-6)12	4(2-5)12	4(2-6)12	4(3-8)12	4(1-6)13	4(2-7)13	4(2-9)12	4(2-5)10

*For full description of station locations, see Table 35.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B12. DISSOLVED SILICA (mg/1), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
9800	6(4-9)14	7(5-9)13	7(6-8)12	7(6-9)13	7(5-8)11	6(4-7)12	6(6-7)12	6(5-7)8
9998	--	--	--	--	6(1-8)9	6(1-9)12	7(5-8)13	6(5-8)10
0550	9(7-11)10	9(4-12)12	10(6-14)12	10(5-13)14	9(6-13)12	8(5-11)12	9(5-12)13	8(4-12)10
0610	--	--	--	--	--	13(13-14)3	11(5-15)12	12(8-16)10
0630	8(4-12)28	7(3-12)12	8(6-12)12	8(5-11)11	8(6-12)11	7(4-10)12	7(4-10)13	6(2-10)9
0680	--	--	--	--	--	7(4-10)7	8(4-11)2	7(-)1
0750	--	--	--	--	--	3(1-5)3	5(1-10)12	6(4-12)11
0760	--	--	--	--	15(7-20)3	14(7-22)14	16(8-22)11	17(11-23)10
0761	--	--	--	--	4(1-6)8	6(3-8)11	4(1-6)11	4(1-9)11
07615	--	--	--	--	23(23-24)3	18(6-28)10	23(15-53)11	22(16-27)9
0767	--	--	--	--	--	9(6-14)4	8(-)1	--
0774	--	--	--	--	7(3-11)3	9(2-17)13	9(5-17)12	9(1-20)10
0781	--	--	--	--	--	10(6-15)5	12(10-15)4	--
0783	--	--	--	--	6(5-8)3	6(2-9)12	4(1-6)12	5(3-6)10
0784	--	--	--	--	--	6(5-7)2	--	4(-)1
0816	--	--	--	--	--	22(-)1	21(17-26)7	13(8-19)5
0817	--	--	--	--	--	--	26(22-30)3	10(8-14)3
0819	--	--	--	--	--	21(-)1	17(15-20)5	8(5-11)3
0840	--	--	--	--	--	12(11-13)3	9(5-15)7	5(4-6)4
0850	7(3-11)12	7(4-10)12	7(5-9)12	6(3-8)12	6(1-11)13	6(4-9)13	5(1-7)12	6(3-7)10

*For full description of station locations, see Table 35.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B13. TOTAL HARDNESS (mg/1), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE AND POWDER RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$(min-max)n†	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n
9800	136(85-172)14	123(77-150)13	123(60-160)12	123(73-146)13	127(60-150)11	128(73-160)12	128(83-180)12	128(73-160)8
9998	--	--	--	--	215(77-340)9	198(94-270)12	214(120-300)13	209(100-250)10
0550	327(76-456)10	298(83-440)12	279(65-360)12	317(82-410)14	301(100-450)12	309(70-440)12	307(89-450)13	305(99-410)10
0610	--	--	--	--	--	640(630-660)3	566(470-690)12	570(320-740)10
0630	309(108-422)28	349(120-490)12	331(130-430)12	317(120-420)11	376(115-510)11	302(100-390)12	330(120-440)13	319(140-390)9
0680	--	--	--	--	--	1189(140-2200)7	1750(1600-1900)2	2000(-)1
0750	--	--	--	--	--	380(360-390)3	310(140-440)12	304(180-380)11
0760	--	--	--	--	730(700-790)3	678(110-1000)14	664(350-840)11	739(520-840)10
0761	--	--	--	--	288(140-410)8	310(130-500)11	316(150-470)11	305(180-390)11
07615	--	--	--	--	767(760-780)3	560(93-730)10	646(590-700)11	654(590-690)9
0767	--	--	--	--	--	358(90-1000)4	250(-)1	--
0774	--	--	--	--	903(780-1000)13	757(120-1000)13	852(650-1100)12	861(650-1100)10
0781	--	--	--	--	--	620(110-1300)5	1375(1300-1500)4	--
0783	--	--	--	--	363(310-430)3	323(140-480)12	330(150-420)12	303(180-410)10
0784	--	--	--	--	--	64(59-70)2	--	61(-)1
0816	--	--	--	--	--	1600(-)1	1643(1300-1900)7	1820(1300-2300)5
0817	--	--	--	--	--	--	1300(1200-1400)3	1113(640-1600)3
0819	--	--	--	--	--	1700(-)1	1220(1100-1400)5	1127(900-1500)3
0840	--	--	--	--	--	420(350-500)3	302(36-620)7	164(47-360)4
0850	338(216-498)12	324(170-450)11	337(150-480)12	332(170-470)12	339(150-520)13	333(130-450)13	330(170-440)12	317(170-420)10

*For full description of station locations, see Table 35.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B14. TOTAL IRON, 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977
	$\bar{x}$(min-max)n †	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n
9800	90(0-190)14	182(30-730)10	--	380(10-750)2	102(0-220)4	93(10-140)3
9998	--	--	--	975(150-1800)2	242(140-400)5	217(120-350)3
0550	130(60-200)10	154(0-280)9	--	950(300-1600)2	285(190-440)4	290(250-330)3
0610	--	--	--	645(580-710)2	912(330-2500)4	6900(-)1
0630	138(100-180)4	246(50-900)10	--	2470(140-4800)2	538(300-710)5	440(230-650)3
0680	--	--	--	1708(220-5000)4	--	--
0750	--	--	--	290(270-310)2	245(60-450)4	550(-)1
0760	--	--	705(540-870)2	1375(580-3600)6	610(350-1100)4	5700(-)1
0761	--	--	--	840(280-1400)2	390(20-980)4	295(100-560)4
07615	--	--	270(200-340)2	968(230-2500)6	315(170-530)4	--
0767	--	--	--	1600(-)1	--	--
0774	--	--	670(620-720)2	1213(280-2900)6	740(310-1300)4	--
0781	--	--	--	1185(770-1600)2	280(-)1	--
0783	--	--	400(280-520)2	3038(110-13000)5	362(90-650)4	6800(-)1
0884	--	--	--	1700(-)1	--	--
0850	--	--	250(-)1	24776(680-74000)5	8430(220-31000)4	1150(190-2900)4

*For full description of station locations, see Table 35.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B15. TOTAL MANGANESE (μg/1), 1974-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1974 $\bar{x}$(min-max)n†	1975 $\bar{x}$(min-max)n	1976 $\bar{x}$(min-max)n	1977 $\bar{x}$(min-max)n
9800	--	45(10-80)2	10(0-20)4	3(0-10)3
9998	--	45(30-60)2	24(10-40)5	17(10-30)3
0550	--	60(60-60)2	48(30-70)4	53(30-70)3
0610	--	125(120-130)2	92(60-120)4	190(-)1
0630	--	125(40-210)2	72(50-110)5	47(40-60)3
0680	--	350(140-850)4	--	--
0750	--	75(60-90)2	65(50-80)4	30(-)1
0760	60(40-80)2	155(40-390)6	100(40-150)4	300(-)1
0761	--	30(20-40)2	42(10-80)4	42(20-70)4
07615	75(30-120)2	72(30-120)6	90(60-140)4	--
0767	--	110(-)1	--	--
0774	70(50-90)2	125(50-360)6	102(40-160)6	--
0781	--	110(80-140)2	50(-)1	--
0783	15(10-20)2	42(10-70)4	32(10-60)4	300(-)1
0784	--	30(-)1	--	--
0850	30(-)1	237(40-680)4	165(10-570)4	50(20-120)4

*For full description of station locations, see Table 35.

†x represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B16. TEMPERATURE (°C), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	[illegible]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
9800	7.5(0.5-16.5)13	6.4(0-16.5)13	5.3(0-14.5)12	5.5(1.0-14.0)13	5.4(0-14.5)14	6.3(1.0-16.0)[illegible]	[illegible](0.5-18.0)12	5.9(0-14.5)12
9998	--	--	--	--	10.5(0-20.5)9	[illegible]	[illegible](0-22.0)11	8.0(0-20.0)11
0550	9.6(1.0-27.0)8	10.3(1.0-21.5)11	10.1(0-22.5)13	7.8(0-22.0)14	9.4(0-26.[illegible]	[illegible]	10.6(0-24.0)27	[illegible]8(0-24.0)17
0610	--	--	--	--		[illegible]	8.[illegible](0-19.0)12	9.9(0-21.0)10
0630	7.0(0-16.0)3	13.0(0-26.0)12	7.4(0-19.5)11	[illegible]		[illegible]	10.8(0-[illegible]	9.4(0-23.0)13
0680	--	--	--			[illegible]	5.5(0-11.0)2	11.0(-)1
0750	--	--	--	--	--	6.0(3.0-12.0)3	9.7(2.0-22.0)12	12.3(2.5-22.5)11
0760	--	--	--	--	4.8(0-10.5)3	6.3(0-22.0)15	9.6(0-21.5)12	13.0(0.25.0)10
0761	--	--	--	--	12.6(0-23.0)9	8.0(0-22.0)12	9.8(0-22.0)12	11.5(0-22.5)11
07615	--	--	--	--	3.7(0-7.0)3	5.2(0-19.0)10	8.0(0-18.0)12	11.7(0-21.0)9
0767	--	--	--	--	--	4.0(0-14.0)4	0(-)1	--
0774	--	--	--	--	2.3(0-5.0)3	7.8(0-24.0)13	9.4(0-24.5)12	13.2(0-26.5)10
0781	--	--	--	--	--	4.8(0-12.5)5	10.4(2.0-15.5)4	--
0783	--	--	--	--	14.1(0-26.0)9	8.1(0-23.0)14	10.7(0-22.5)12	13.2(0-25.0)10
0784	--	--	--	--	--	0(0-0)2	--	0.5(-)1
0816	--	--	--	--	--	0.5(-)1	10.9(0-26.0)7	6.7(0-20.5)5
0817	--	--	--	--	--	--	9.2(0.5-26.0)3	2.3(0.5-5.5)3
0819	--	--	--	--	--	0(-)1	11.4(0-27.0)5	9.8(0-17.0)3
0840	--	--	--	--	--	3.2(0.5-6.0)3	12.3(0-29.5)7	7.8(0-25.0)4
0850	9.4(0-28.0)9	10.4(0-24.0)12	10.2(0-24.0)12	10.0(0-27.0)12	10.6(0-25.0)13	8.6(0-23.5)13	9.7(0-27.0)12	11.5(0-25.0)11

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*For full description of station locations, see Table 35.

[†] x represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B17. DISSOLVED OXYGEN (mg/1), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
9800	--	--	--	12.1(11.8-12.4)3	10.2(7.3-12.3)14	10.8(8.4-13.0)12	9.7(7.6-12.0)12	10.1(8.4-11.4)8
9998	--	--	--	--	10.2(8.5-13.6)8	10.5(7.9-12.2)12	10.0(8.0-11.9)13	9.8(8.0-11.8)12
0350	--	--	--	12.4(10.4-13.5)3	10.5(8.6-14.4)13	11.2(6.7-13.6)12	9.4(7.0-12.3)13	9.3(6.1-11.6)12
0610	--	--	--	--	--	10.0(8.0-11.0)3	9.9(7.4-11.7)12	9.4(7.8-11.6)10
0630	--	--	--	11.6(11.0-12.0)3	9.9(7.8-12.8)13	9.7(6.0-12.2)12	9.4(7.0-11.8)13	9.9(6.6-12.4)12
0680	--	--	--	--	--	10.5(8.6-12.0)7	7.2(6.3-8.0)2	9.6(-)1
0750	--	--	--	--	--	10.9(8.8-12.0)3	10.4(8.0-12.5)12	10.5(6.8-13.2)11
0760	--	--	--	--	10.9(9.6-12.0)3	9.8(5.8-13.2)14	8.8(5.1-11.6)12	8.9(6.2-12.8)10
0761	--	--	--	--	9.8(7.6-12.2)9	10.1(7.2-12.4)12	10.1(7.3-12.8)12	9.6(7.0-12.2)11
07615	--	--	--	--	12.6(12.0-13.8)3	10.9(6.8-13.4)10	9.7(5.1-12.0)12	9.1(6.0-12.2)9
0767	--	--	--	--	--	10.0(6.3-11.8)4	6.8(-)1	--
0774	--	--	--	--	10.4(7.4-12.0)3	10.0(5.0-12.4)13	8.9(3.0-12.7)12	8.6(5.2-13.4)9
0781	--	--	--	--	--	9.8(7.2-11.6)5	8.0(6.0-10.2)4	--
0783	--	--	--	--	9.5(7.4-12.3)9	9.6(6.8-12.8)13	9.9(7.4-12.5)12	9.6(7.6-12.1)10
0784	--	--	--	--	--	11.9(11.8-12.0)2	--	10.6(-)1
0816	--	--	--	--	--	6.8(-)1	5.7(3.7-8.2)7	5.7(0-12.4)5
0817	--	--	--	--	--	--	7.5(5.1-9.3)3	8.2(6.4-9.8)3
0819	--	--	--	--	--	8.3(-)1	8.8(7.4-12.4)5	8.6(7.2-10.2)3
0840	--	--	--	--	--	11.2(9.6-12.4)3	9.3(7.3-12.0)7	10.2(8.4-11.8)4
0850	--	--	--	--	9.8(7.4-13.0)10	10.5(6.5-13.2)13	11.2(7.9-15.6)12	10.2(7.6-12.4)11

*For full description of station locations, see Table 35.
†x represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B18. pH, 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
9800	8.0(7.3-8.5)14	8.2(8.0-8.4)13	8.2(7.9-8.4)12	8.3(8.0-8.6)13	8.1(7.4-8.4)13	7.6(6.8-8.1)12	8.0(7.7-8.2)12	7.9(7.5-8.1)9
9998	--	--	--	--	7.9(7.5-8.5)9	7.8(6.9-8.8)12	8.0(7.8-8.2)13	7.9(7.6-8.2)13
0550	7.9(6.7-8.4)10	7.8(7.4-8.3)12	7.9(7.4-8.4)12	8.1(7.5-8.5)14	8.1(7.7-8.5)13	7.8(6.8-8.4)12	8.1(7.7-8.6)13	8.0(7.5-8.3)13
0610	--	--	--	--	--	8.2(8.0-8.5)3	8.2(7.9-8.5)12	8.3(7.7-8.6)10
0630	8.2(7.0-8.6)28	8.2(7.5-8.4)11	8.1(7.7-8.4)12	8.2(7.9-8.5)12	8.0(7.6-8.4)12	7.8(7.0-8.2)12	8.0(7.7-8.5)13	8.0(7.6-8.3)13
0680	--	--	--	--	--	8.0(7.4-8.3)7	8.1(7.9-8.4)2	8.2(-)1
0750	--	--	--	--	--	8.3(8.1-8.5)3	8.2(7.9-8.6)12	8.2(7.8-8.8)11
0760	--	--	--	--	8.2(8.0-8.4)3	8.0(7.4-8.3)14	8.2(8.0-8.3)12	8.2(8.0-8.5)10
0761	--	--	--	--	8.3(8.0-8.6)9	8.1(7.7-8.5)12	8.4(8.0-8.7)12	8.4(8.0-8.7)11
07615	--	--	--	--	8.4(8.3-8.6)3	7.9(7.7-8.2)10	8.1(7.7-8.3)12	8.3(8.0-8.6)9
0767	--	--	--	--	--	7.7(7.0-8.3)4	8.4(-)1	--
0774	--	--	--	--	8.4(8.2-8.6)3	8.0(7.2-8.6)13	8.3(8.0-8.4)12	8.3(7.9-8.6)9
0781	--	--	--	--	--	8.0(7.7-8.3)5	8.1(8.0-8.1)4	--
0783	--	--	--	--	8.2(7.8-8.6)9	8.0(7.3-8.4)13	8.1(7.9-8.4)12	8.3(7.9-8.6)9
0784	--	--	--	--	--	8.0(7.7-8.2)2	--	8.4(-)1
0816	--	--	--	--	--	8.0(-)1	7.8(7.5-8.1)7	7.7(7.2-8.3)5
0817	--	--	--	--	--	--	8.0(7.8-8.1)3	7.7(7.3-8.1)3
0819	--	--	--	--	--	8.0(-)1	8.1(8.0-8.4)5	7.9(7.1-8.3)3
0840	--	--	--	--	--	8.4(8.1-8.6)3	8.2(7.8-8.5)7	8.3(8.0-8.7)4
0850	7.9(7.0-8.2)12	8.0(7.8-8.6)12	7.9(7.2-8.3)12	8.0(7.5-8.4)12	8.2(7.9-8.6)13	8.3(8.0-8.5)13	8.2(7.7-8.5)12	8.3(7.8-8.6)11

*For full description of station locations, see Table 35.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B19. TOTAL ALKALINITY (mg/1), 1970-77, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE TONGUE RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977
	$\bar{x}$(min-max)n†	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n	$\bar{x}$(min-max)n
9800	125(80-145)14	120(75-140)13	117(62-139)12	117(70-135)13	122(57-138)11	124(74-164)12	127(82-172)12	125(71-148)8
9998	--	--	--	--	163(70-213)9	164(83-205)12	178(103-244)13	176(90-210)10
0550	219(61-272)10	197(74-262)12	190(53-240)12	219(60-264)14	215(75-271)12	218(53-295)12	219(70-295)13	221(65-279)10
0610	--	--	--	--	444(432-457)3	368(304-480)12	366(200-499)10	377(200-499)25
0630	185(90-259)27	210(84-271)12	208(94-249)12	204(88-251)11	236(93-271)11	202(82-262)12	219(90-281)13	221(107-279)9
0680	--	--	--	--	--	333(71-523)7	492(473-511)2	540(-)1
0750	--	--	--	--	--	238(225-246)3	202(107-272)12	187(110-258)11
0760	--	--	--	--	529(518-549)3	393(73-549)14	458(206-531)12	495(280-540)10
0761	--	--	--	--	187(107-234)9	203(100-325)11	211(102-304)12	203(120-260)11
07615	--	--	--	--	533(522-541)3	428(75-550)10	536(483-582)12	548(504-600)9
0767	--	--	--	--	--	184(57-479)4	--	--
0774	--	--	--	--	568(539-614)3	443(90-664)13	528(372-618)12	555(452-650)10
0781	--	--	--	--	--	307(77-613)5	578(533-619)4	--
0783	--	--	--	--	234(211-274)4	214(102-326)13	217(111-277)12	209(120-279)10
0784	--	--	--	--	--	53(49-57)2	45(-)1	--
0850	234(161-319)12	220(125-303)11	223(114-318)12	234(129-325)12	234(114-367)13	227(116-306)13	230(143-295)12	214(120-281)10

*For full description of station locations, see Table 35.

†x represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B20. FLOW (m^3/sec), 1972-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	--	3.1(2.8-3.3)3	1.8(0.02-4.0)12	4.8(0.01-22.1)12	3.9(0.1-18.7)12	4.9(0.1-29.7)12	2.4(1.7-3.1)3
1300	--	0.2(0.01-0.6)4	0.3(0-0.8)11	0.3(0-1.5)11	0.3(0-1.4)12	0.2(0-1.0)12	9.5(0.03-28.3)3
1340	--	0.4(0.2-0.7)2	0.7(0.3-1.3)12	0.9(0.2-2.1)12	2.1(0.3-11.3)21	1.4(0.4-6.4)12	19.0(-)1
1350	--	--	--	--	1.4(-)1	3.9(3.5-4.2)4	5.1(2.8-7.5)2
1640	2.5(0.2-21.8)12	0.5(0.3-0.7)12	0.7(0.01-2.8)11	1.7(0.1-7.2)12	1.7(0.3-5.1)12	0.8(0.002-1.7)10	0.4(0.3-0.4)2
1700	--	6.7(2.3-10.1)4	9.9(0.3-58.1)14	9.0(0.1-56.1)14	13.8(0.5-71.9)17	11.0(0.4-54.9)7	10.8(0.1-71.9)56
2020	--	--	--	1.5(1.3-1.6)2	2.4(0.4-6.6)17	1.7(0.5-7.1)12	2.0(0.4-7.1)31
2040	--	--	--	1.1(0.8-1.4)2	2.9(0.3-8.5)11	1.6(0.3-5.1)11	2.2(0.3-8.5)24
2350	--	--	--	4.9(1.1-25.3)8	3.2(0.6-11.5)13	1.5(0.6-7.1)13	3.0(0.6-25.3)34
2400	--	2.9(2.1-3.5)12	4.6(1.4-10.4)11	8.6(0.4-100.2)13	5.4(0.3-18.5)22	2.8(0.5-14.6)11	7.6(0.3-100.2)18
2450	--	10.3(2.3-44.2)11	--	54.6(1.8-342.7)16	13.5(0.7-52.7)13	16.1(0.6-132.2)13	4.9(4.8-5.1)2
2492	--	--	--	0.1(-)1	0.3(0.01-0.8)4	0.1(0.002-0.2)6	0.02(-)1
2497	--	--	--	0.3(0-2.7)22	0.7(0.01-10.7)54	0.3(0.01-1.0)13	0.6(0-10.7)89
2605	--	--	--	0.004(0.003-0.01)2	0.01(0.001-0.01)6	0.005(0-0.02)4	0.005(0-0.02)12
2620	--	--	--	0.003(-)2	0.05(0.001-0.2)10	0.001(0-0.001)5	0.03(0-0.2)17
2630	--	--	--	0.02(0.01-0.04)3	0.5(0.02-1.9)6	0.3(0.001-0.6)8	0.005(-)1
2650	--	--	7.0(4.9-8.7)4	48.1(0.9-305.8)13	16.1(0.7-68.5)12	12.6(0.8-56.1)12	4.1(3.4-4.7)2

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B21. TOTAL DISSOLVED SOLIDS (mg/1), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	806(267-1240)12	808(252-1220)10	941(491-1306)12	748(313-1100)12	794(281-1160)12	738(233-1040)8	802(233-1306)90
1300	2629(1880-3320)10	2893(1970-3790)8	2765(2040-3180)8	2777(1970-3679)8	2572(1630-3380)10	2462(1460-3440)5	2604(1460-4390)73
1340	4571(2640-5580)12	4711(3160-5340)10	4700(4450-5540)12	4295(3849-4640)12	3855(1820-5470)11	3961(2860-4550)9	4478(1820-5660)90
1350	--	--	--	--	2590(-)1	2670(1630-3710)2	2643(1630-3710)3
1640	1850(755-4060)10	1614(416-3000)8	1350(300-2360)11	1026(330-1950)12	982(400-1440)13	1232(539-1890)8	1258(289-4060)85
1700	1976(737-4050)30	1718(1130-2070)7	2353(1580-3269)11	1908(609-2810)14	1826(1140-2320)13	1864(740-3110)9	1910(609-4050)108
2020	--	--	--	672(631-713)2	499(208-806)13	667(133-913)14	602(544-711)4
2040	--	--	--	775(700-850)2	612(306-992)10	840(175-1190)11	743(723-800)4
2350	--	--	--	368(78-525)7	284(105-586)13	354(126-463)12	364(357-376)3
2400	872(170-1520)10	990(515-1600)9	668(258-826)11	692(143-997)12	732(201-1340)15	891(319-1150)7	775(143-1600)87
2450	--	--	1159(745-1460)12	1296(625-1670)14	1413(973-2130)11	1607(854-2510)12	1590(1480-1700)2
2492	--	--	--	2090(-)1	2466(1930-2859)3	960(620-1300)2	1901(620-2859)6
2497	--	--	--	2127(1330-3440)14	2222(621-3100)39	1700(567-3220)19	2317(1800-2650)3
2605	--	--	--	4760(4720-4800)2	3171(2390-4120)6	2912(2050-3640)4	3350(2050-4800)12
2620	--	--	--	2050(1970-2130)2	1989(888-2470)10	2202(2100-2470)5	2059(888-2470)17
2630	--	--	--	2463(2350-2550)3	1117(191-2280)6	1162(274-2380)5	1421(191-2550)14
2650	--	--	1420(1340-1580)3	1263(641-1760)12	1330(519-2130)12	1545(905-2030)11	1378(519-2130)38

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B22. CONDUCTIVITY (μmho/cm at 25°C), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	1170(447-1700)12	1131(393-1600)10	1334(742-1750)9	483(-)1	--	--	1163(393-1770)56
1300	3181(2350-3800)10	3386(2270-4570)8	3227(2520-3550)6	4067(3400-5000)3	3450(2300-4500)10	2930(11-5200)7	3189(11-5460)68
1340	7202(3910-8250)12	6770(4000-8160)10	6904(6302-8100)9	8000(-)1	6160(2600-8000)10	6354(2600-8000)13	6731(2600-8370)79
1350	--	--	--	--	4100(-)1	4790(2580-7000)2	4560(2580-7000)3
1640	2218(1060-4170)10	1931(590-3340)8	1676(508-2670)8	--	1060(-)1	1910(1720-2100)2	1722(443-4170)52
1700	2766(1070-5360)30	2419(1600-2950)7	3242(2230-4430)8	2820(1000-4000)5	2752(1700-3500)12	2729(1250-4000)12	2696(1000-5360)103
2020	--	--	--	1025(1000-1050)2	721(340-1180)13	939(220-1300)14	878(750-1000)4
2040	--	--	--	1085(1070-1100)2	877(460-1450)10	1175(300-1600)12	938(750-1020)4
2350	--	--	--	574(120-805)8	458(190-900)13	563(220-805)13	500(300-600)4
2400	1170(279-1940)10	1321(733-2020)9	947(460-1200)11	992(230-1350)12	1049(340-1850)12	1340(480-1850)12	1099(230-2020)89
2450	2114(1060-5000)16	1794(775-2580)19	1748(1170-2800)12	1884(945-2500)15	1931(730-2680)12	2312(1310-3490)12	2375(2250-2500)2
2492	--	--	--	2600(-)1	2660(2000-3010)5	1212(825-1600)2	2291(825-3010)8
2605	--	--	--	5135(4700-5570)2	3803(3000-4960)6	4060(2680-5810)4	4111(2680-5810)12
2620	--	--	--	3005(2710-3300)2	2821(1370-3900)10	3310(2870-3900)5	2986(1370-3900)17
2630	--	--	--	3693(3400-4100)3	1580(319-3050)6	1752(710-3400)7	2051(319-4100)16
2650	--	--	2273(2200-2370)3	1742(920-2400)12	1879(760-2900)12	2174(1380-2650)11	1952(760-2900)38

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B23. DISSOLVED CALCIUM (mg/1), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	112(58-150)12	104(45-140)10	125(66-155)12	107(54-130)12	107(47-170)12	94(45-120)8	108(45-170)90
1300	336(271-442)10	356(200-550)8	312(240-390)8	298(190-410)8	262(180-330)10	262(140-320)5	298(140-550)73
1340	86(48-127)12	111(62-170)10	57(23-110)12	69(30-100)12	88(51-150)11	88(41-140)9	86(23-170)90
1350	--	--	--	--	150(-)1	96(72-120)2	114(72-150)3
1640	206(91-440)10	199(67-340)8	175(58-300)11	133(47-260)12	124(52-180)13	156(72-230)8	156(47-440)85
1700	168(99-280)30	150(100-180)7	168(120-280)11	139(71-210)14	160(100-200)13	139(70-180)9	156(70-280)108
2020	--	--	--	102(94-110)2	75(31-110)13	98(21-130)14	92(82-110)4
2040	--	--	--	115(100-130)2	91(45-140)10	120(28-170)11	112(110-120)4
2350	--	--	--	51(13-69)7	44(18-75)13	55(23-72)12	57(56-58)3
2400	102(29-180)10	125(67-180)9	95(46-120)11	94(24-120)12	99(31-170)15	116(50-140)7	102(24-180)87
2450	175(130-228)6	120(65-150)11	113(80-150)12	124(52-160)14	124(50-190)12	152(110-220)12	155(140-170)2
2492	--	--	--	190(-)1	270(130-400)3	68(65-72)2	190(65-400)6
2497	--	--	--	158(100-260)14	169(46-320)39	134(55-260)19	183(140-210)3
2605	--	--	--	345(320-370)2	268(200-380)6	242(170-320)4	272(170-380)12
2620	--	--	--	145(140-150)2	113(45-170)10	138(120-150)5	124(45-170)17
2630	--	--	--	62(39-82)3	39(14-68)6	32(9-64)5	42(9-82)14
2650	--	--	130(120-150)3	110(64-160)12	119(48-160)12	133(97-180)11	121(48-180)38

*For full description of station locations, see Table 36.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B24. DISSOLVED SODIUM (mg/1), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	87(15-170)12	95(18-180)10	109(55-190)12	80(20-140)12	94(24-140)12	96(14-150)8	92(14-190)90
1300	350(190-493)10	416(200-600)8	414(260-480)8	451(310-660)8	446(250-660)10	428(270-630)5	396(190-880)73
1340	1555(710-1840)12	1491(710-1700)10	1618(1500-2000)12	1440(1200-1600)12	1221(420-1800)11	1278(790-1500)9	1465(420-2000)90
1350	--	--	--	--	680(-)1	840(380-1300)2	787(380-1300)3
1640	180(71-380)10	147(32-260)8	125(27-240)11	94(24-180)12	95(33-150)13	119(52-180)8	117(12-380)85
1700	386(96-932)30	337(230-430)7	505(315-788)11	403(91-590)14	351(220-470)13	409(140-740)9	384(91-932)108
2020	--	--	--	54(52-56)2	38(16-64)13	54(10-80)14	46(43-53)4
2040	--	--	--	62(57-68)2	49(24-83)10	68(13-100)11	60(57-62)4
2350	--	--	--	34(6-53)7	24(8-58)13	29(9-42)12	29(28-30)3
2400	84(12-162)10	94(49-190)9	58(20-81)11	61(9-95)12	65(15-130)15	88(23-130)7	70(9-190)87
2450	3(-)1	176(66-250)4	201(88-280)12	225(91-320)14	241(74-430)12	282(120-490)12	285(270-300)2
2492	--	--	--	340(-)1	290(160-380)3	196(93-300)2	267(93-380)6
2497	--	--	--	380(240-590)14	382(120-560)39	298(89-530)19	423(340-480)3
2605	--	--	--	600(-)2	378(280-510)6	322(220-400)4	397(220-600)12
2620	--	--	--	440(420-460)2	437(200-540)10	482(450-550)5	450(200-550)17
2630	--	--	--	693(670-720)3	289(43-570)6	330(60-690)5	390(43-720)14
2650	--	--	263(250-280)3	237(110-350)12	246(110-420)12	289(150-410)11	257(110-420)38

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B25. DISSOLVED MAGNESIUM (mg/1), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n †	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max)n
1250	43(13-57)12	43(13-60)10	43(14-70)12	42(17-53)12	49(28-66)12	41(15-62)12	39(14-62)12	37(12-51)8	42(12-69)90
1300	90(14-159)10	76(45-110)8	78(49-140)11	82(37-140)13	96(63-140)8	86(54-120)8	72(52-90)10	68(29-99)5	82(14-159)73
1340	52(10-78)12	69(39-140)10	60(27-86)12	69(54-110)12	50(33-65)12	53(31-110)12	50(32-84)11	48(34-79)9	56(10-140)90
1350	--	--	--	--	--	--	59(-)1	53.5(53-54)2	55(53-59)3
1640	124(45-260)10	105(22-220)8	74(12-130)12	77(37-140)11	84(9-140)11	66(22-110)12	62(25-94)13	75(32-120)8	82(9-260)85
1700	67(30-112)30	57(33-74)7	57(37-76)12	62(25-100)12	79(26-120)11	63(22-100)14	63(38-90)13	56(32-95)9	64(22-120)108
2020	--	--	--	--	--	42(39-44)2	32(13-53)13	44(8-64)14	41(35-49)4
2040	--	--	--	--	--	49(45-53)2	40(20-68)10	57(11-79)11	52(50-59)4
2350	--	--	--	--	--	25(4-37)7	19(6-40)13	25(8-33)12	27(27-27)3
2400	63(10-117)10	65(34-94)9	45(13-85)12	58(13-95)11	42(9-58)11	46(8-73)12	48(13-89)15	61(21-82)7	52(8-117)87
2450	85(56-132)6	52(12-100)11	47(25-72)7	--	54(28-70)12	56(24-90)14	54(16-91)12	68(31-110)12	74(69-79)2
2492	--	--	--	--	--	110(-)1	135(75-180)3	34(20-47)2	97(20-180)6
2497	--	--	--	--	--	97(58-160)14	105(23-180)39	76(18-160)19	106(79-120)3
2605	--	--	--	--	--	360(-)2	242(180-310)6	235(150-310)4	259(150-360)12
2620	--	--	--	--	--	72.5(72-73)2	74(31-91)10	86(82-95)5	77(31-95)17
2630	--	--	--	--	--	52(42-65)3	28(6-69)6	20(4-41)5	30(4-69)14
2650	--	--	--	--	59(51-73)3	50(26-71)12	51(14-87)12	57(32-78)11	53(14-87)[illegible]8

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*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B26. DISSOLVED POTASSIUM (mg/1), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	2.6(1.5-4.4)12	2.8(1.3-4.7)10	3.2(2.3-4.4)12	3.0(1.6-4.2)12	3.3(2.3-4.9)12	3.0(1.4-4.3)8	3.0(1.3-4.9)90
1300	7.4(4.6-9.8)10	8.4(4.2-13.0)8	7.9(5.4-9.8)8	8.6(5.6-15.0)8	7.9(5.8-12.0)10	7.7(5.6-11.0)5	7.9(0.9-15.0)73
1340	19.8(10.0-24.0)12	24.5(11.0-50.0)10	15.5(12.0-19.0)12	16.2(12.0-21.0)12	17.3(6.7-26.0)11	17.2(10.0-20.0)9	17.9(1.6-50.0)90
1350	--	--	--	--	13.0(-)1	11.4(6.7-16.0)2	11.9(6.7-16.0)3
1640	5.7(2.8-12.0)10	4.4(2.2-7.9)8	4.6(2.8-7.2)11	3.4(2.1-5.1)12	3.9(2.3-6.3)13	4.9(3.0-8.1)8	4.2(2.1-12.0)85
1700	7.3(4.2-14.0)30	6.4(4.7-8.7)7	8.0(4.9-12.0)11	7.0(3.7-10.0)14	7.2(4.7-10.0)13	6.9(1.3-12.0)9	7.1(1.3-14.0)108
2020	--	--	--	3.3(3.2-3.4)2	3.6(1.8-12.0)13	3.1(1.7-4.4)14	2.8(2.4-3.1)4
2040	--	--	--	4.4(4.4-4.4)2	4.2(2.6-7.3)10	4.4(0.5-6.7)11	3.6(3.3-4.0)4
2350	--	--	--	4.4(1.1-6.4)7	3.7(2.0-7.7)13	3.9(2.0-5.0)12	3.6(3.4-3.7)3
2400	4.5(1.3-8.8)10	5.3(2.4-8.2)9	4.7(2.1-7.9)11	4.1(1.6-7.4)12	4.4(1.9-9.0)15	4.5(2.3-7.2)7	4.5(1.3-9.0)87
2450	--	--	6.1(3.4-9.2)12	6.9(3.8-17.0)14	6.7(3.1-11.0)12	7.4(4.9-11.0)12	6.6(6.5-6.8)2
2492	--	--	--	21.0(-)1	38.0(16.0-49.0)4	10.8(9.7-12.0)2	27.8(9.7-49.0)7
2497	--	--	--	18.4(15.0-25.0)14	22.4(11.0-43.0)39	16.0(8.7-26.0)19	17.3(16.0-19.0)3
2605	--	--	--	21.0(20.0-22.0)2	13.8(11.0-19.0)6	13.2(8.1-20.0)4	14.8(8.1-22.0)12
2620	--	--	--	9.0(8.8-9.3)2	10.3(9.1-12.0)10	8.8(8.0-9.5)5	9.7(8.0-12.0)17
2630	--	--	--	9.2(8.9-9.3)3	7.6(4.7-13.0)6	5.6(2.4-9.4)5	7.2(2.4-13.0)14
2650	--	--	8.0(6.7-8.7)3	6.8(4.3-8.6)12	7.1(4.5-12.0)12	7.9(5.5-11.0)11	7.3(4.3-12.0)38

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B27. BICARBONATE ION (mg/1), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	230(174-281)12	220(122-268)10	237(168-281)12	220(130-270)12	208(130-280)12	212(100-280)8	220(100-287)90
1300	214(134-326)10	210(143-345)8	200(168-250)8	202(92-340)8	196(130-290)10	192(150-230)5	194(92-345)73
1340	669(397-847)12	647(330-955)10	1092(787-1410)12	915(680-1210)12	611(220-1000)11	727(420-960)9	790(220-1410)90
1350	--	--	--	--	422(-)1	510(360-600)2	481(360-660)3
1640	250(140-374)10	254(119-415)8	252(120-360)11	219(120-300)12	208(110-310)13	232(150-370)8	230(74-415)85
1700	244(147-366)30	269(189-427)7	343(150-620)11	306(150-580)14	276(172-450)13	299(190-480)9	278(145-620)108
2020	--	--	--	233(216-250)2	170(82-242)13	213(51-290)14	222(210-250)4
2040	--	--	--	262(241-282)2	210(127-329)10	261(69-350)11	255(250-270)4
2350	--	--	--	171(43-215)7	158(76-241)13	208(84-299)12	223(220-230)3
2400	217(82-305)10	261(165-307)9	223(110-265)11	212(61-270)12	215(90-310)15	264(150-330)7	226(61-330)87
2450	--	--	262(134-351)12	274(142-427)14	259(204-365)12	277(150-432)12	395(360-430)2
2492	--	--	--	453(-)1	373(276-437)3	180(110-250)2	322(110-453)6
2497	--	--	--	419(173-565)14	364(137-610)39	336(120-633)19	520(410-580)3
2605	--	--	--	596(535-658)2	493(287-762)6	550(310-1010)4	529(287-1010)2
2620	--	--	--	622(608-637)2	520(244-729)10	658(605-720)5	572(244-729)17
2630	--	--	--	644(507-788)3	313(87-493)6	322(147-704)7	379(87-788)16
2650	--	--	323(282-386)3	268(158-453)12	278(186-396)12	268(150-430)11	276(150-454)38

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B28. SULFATE (mg/l), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	386(78-629)12	393(92-620)10	461(223-672)12	355(120-560)12	394(110-580)12	349(94-520)8	389(78-672)90
1300	1613(1100-2050)10	1775(1200-2300)8	1675(1200-1900)8	1662(1200-2300)8	1590(1000-2000)10	1436(880-2000)5	1584(880-2300)73
1340	1225(1080-1400)12	1300(1100-1600)10	1072(890-1400)12	1037(800-1310)12	1160(930-1900)11	1072(830-1700)9	1199(800-1900)90
1350	--	--	--	--	900(-)1	760(570-950)2	807(570-950)3
1640	1177(444-2700)10	1015(220-2000)8	818(130-1500)11	598(160-1200)12	578(210-890)13	736(290-1200)8	764(130-2700)85
1700	936(371-1940)30	764(490-910)7	1056(690-1500)11	854(270-1400)14	869(530-1100)13	816(310-1400)9	887(270-1940)108
2020	--	--	--	340(320-360)2	249(88-430)13	347(56-490)14	292(260-350)4
2040	--	--	--	400(360-440)2	311(140-520)10	447(78-670)11	370(360-400)4
2350	--	--	--	161(26-250)7	105(24-290)13	127(31-190)12	123(120-130)3
2400	497(69-965)10	558(270-990)9	347(110-454)11	371(60-560)12	396(86-830)15	476(130-640)7	421(60-990)87
2450	620(195-1170)9	613(280-1100)10	535(370-680)12	611(290-850)14	669(480-1100)11	798(440-1300)12	670(620-720)2
2492	--	--	--	1200(-)1	1533(1100-1900)3	550(360-740)2	1150(360-1900)6
2497	--	--	--	1347(760-2100)14	1344(340-2000)39	991(320-1900)19	1300(1000-1500)3
2605	--	--	--	3100(3000-3200)2	2000(1500-2500)6	1775(1300-2200)4	2108(1300-3200)12
2620	--	--	--	1050(1000-1100)2	1079(470-1300)10	1140(1100-1300)5	1094(470-1300)17
2630	--	--	--	1300(-)1	582(73-1300)6	560(120-1200)7	683(73-1300)16
2650	--	--	647(590-720)3	612(320-970)12	665(220-1200)12	793(490-1100)11	684(220-1200)38

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

U.S. DEPARTMENT OF COMMERCE

PB80-166598

Assessment of Energy Resource Development Impact on Water Quality The Tongue and Powder River Basins

(U.S.) Environmental Monitoring and Support Lab.
Las Vegas, NV

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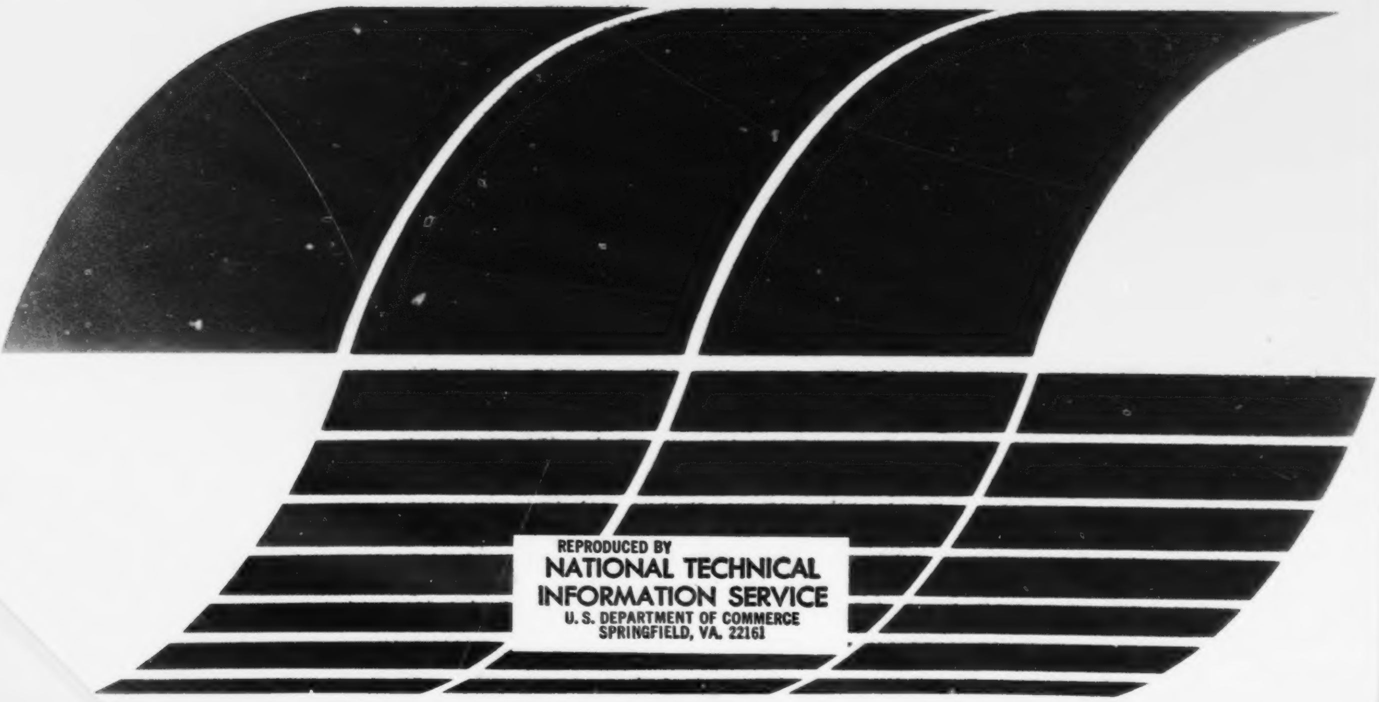
Assessment of Energy Resource Development Impact on Water Quality:

The Tongue and Powder River Basins

Interagency Energy-Environment Research and Development Program Report



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16. ABSTRACT

The Tongue and Powder River Basins contain vast beds of low-sulfur, stripable coal that potentially will support a large number of powerplants, gasification, and liquefaction complexes for conversion of this coal into commercially usable power. Development of local oil and gas fields, as well as some uranium exploration, is also ongoing. However, utilization of these energy resources, especially if maximum levels of expansion are realized, is expected to have considerable impact on water resources in the Tongue and Powder River Basins. It appears unlikely that there are sufficient surface or ground water supplies to meet projected needs in the area without creation of additonal reservoir storage or diversion of surface water from other sources. Water quality and quantity impacts from energy developments will reduce water usability for municipal, industrial, and irrigation purposes and will have adverse impacts on the aquatic ecosystem. Alternative proposals for maintenance of valid instream flow requirements in the basins, however, could greatly limit annual quantities of water available for diversion for energy users. The existing U.S. Geological Survey sampling network is adequately situated for evaluating the impact of energy development activities and should be carefully monitored on a regular basis in the future. Priority listings of parameters to be measured to detect changes in water quality as a result of energy resource development and to assess future projects are recommended.

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Water resources	Powder River	17B
Water quality	Rosebud Creek	21D
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ASSESSMENT OF ENERGY RESOURCE DEVELOPMENT IMPACT ON WATER QUALITY

The Tongue and Powder River Basins

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FOREWORD

Protection of the environment requires effective regulatory actions that are based on sound technical and scientific data. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach that transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment

- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report presents an evaluation of surface water quality in the Tongue and Powder River Basins and discusses the impact of energy development upon water quality and water availability. The water quality data collected to date and presented in this report may be considered baseline in nature and used to evaluate future impacts on water quality. This report was written for use by Federal, State, and local government agencies concerned with energy resource development and its impact on western water quality. Private industry and individuals concerned with the quality of western rivers may also find the document useful. This is one of a series of reports funded by the Interagency Energy-Environment Research and Development Program. For further information contact the Water and Land Quality Branch, Monitoring Operations Division.

George B. Morgan
Director
Environmental Monitoring and Support Laboratory
Las Vegas

SUMMARY

Development of fossil fuel, uranium, and other energy reserves located in the Western United States is essential. These resources are located primarily in the Northern Great Plains and the Colorado Plateau. Because of our national dependence upon oil and gas, conversion of coal to these liquid and gaseous forms is anticipated.

Development of these resources cannot be accomplished without some environmental impact. The potential for serious degradation of air, land, or water quality exists. Pollution may occur during any or all stages of the extraction, refining, transportation, conversion, or utilization processes. Secondary impacts resulting from increased population pressures, water management, and development of supportive industries are expected. Potential contamination of ground-water supplies from in situ coal conversion facilities and nonpoint pollution from sources such as stack emissions, airborne dust, and localized "spills" are of particular concern in the Tongue and Powder River Basins. With careful planning and regulation, such impacts can be minimized and held within tolerable levels.

The primary objective of this report is to evaluate the existing water quality monitoring network in the Tongue and Powder River Basins and to recommend needed modifications to the present sampling program. As a basis for these recommendations, known developments, both present and planned, are discussed, and available data examined. The impact of developers on both water quality and quantity is defined. Two areas of particular concern are coal strip mining activities in the vicinity of Sheridan and oil field operations in the Salt Creek watershed.

A monitoring network designed to detect trends in surface water quality is proposed on the basis of our present knowledge. Such a network minimizes the number of observations at the expense of the number of stations in order to provide statistically valid data. This network consists of 21 stations (including stations in Armells, Sarpy, and Rosebud Creek drainages):

USGS Station#	Description
06294940	Sarpy Creek near Hysham, MT
06294980	East Fork Armells Creek near Colstrip, MT
06294995	Armells Creek near Forsyth, MT
06295400	Rosebud Creek above Pony Creek, MT
06296003	Rosebud Creek at mouth, near Rosebud, MT
06299980	Tongue River at Monarch, WY
06305500	Goose Creek below Sheridan, WY
06306300	Tongue River at State line near Decker, MT

USGS Station#	Description
06307610	Tongue River below Hanging Woman Creek, MT
06308400	Pumpkin Creek near Miles City, MT
06308500	Tongue River at Miles City, MT
06312500	Powder River near Kaycee, WY
06313400	Salt Creek near Sussex, WY
06313500	Powder River at Sussex, WY
06324000	Clear Creek near Arvada, WY
06324500	Powder River at Moorhead, MT
06326300	Mizpah Creek near Mizpah, MT
06326500	Powder River near Locate, MT
06295000	Yellowstone River at Forsyth, MT
06326530	Yellowstone River at Terry, MT
not established	Powder River at mouth, MT

A similar network for ground-water monitoring needs to be implemented; however, presently available data are insufficient to adequately determine station locations.

Biological, physical, and chemical parameters likely to be affected by energy resources development activities were determined. Salinity and suspended sediment concentrations are already a problem in the Powder River Basin, and a number of trace elements are regularly found in excessively high concentrations throughout both basins, particularly during high runoff periods. Physical and chemical parameters recommended as top priority for monitoring are:

- Total alkalinity
- Total aluminum
- Total ammonia
- Total arsenic
- Total beryllium
- Bicarbonate
- Biological oxygen demand of bottom sediments
- Total boron
- Total cadmium
- Total organic carbon in bottom sediments
- Dissolved calcium
- Chloride
- Total chromium
- Specific conductance
- Total copper
- Total cyanide
- Flow
- Fluoride
- Total iron
- Total lead
- Dissolved magnesium
- Total manganese
- Total mercury
- Total molybdenum
- Dissolved oxygen
- Total nickel
- Pesticides
- Petroleum hydrocarbons
- pH
- Total phosphorus
- Dissolved potassium
- Total selenium
- Dissolved sodium
- Dissolved sulfate
- Suspended sediments
- Temperature
- Total dissolved solids
- Total zinc

Biological monitoring is considered to be presently the most feasible method of assessing the impact of the introduction of an extensive number of organic chemicals into the environment such as may result from in situ coal conversion activities. Those biological analyses recommended as having top priority for monitoring water quality in the Tongue and Powder River Basins include:

Macroinvertebrates - Counts and identifications, biomass
Periphyton - Biomass, growth rate, identification and relative abundance determinations
Fish - Identification and enumeration, toxic substances in tissue
Macrophytes - Species identification and community association
Zooplankton (lentic only) - Identification and count
Phytoplankton (lentic only) - Chlorophyll a, identification and enumeration
Microorganisms - Total fecal coliform

In order to obtain sufficient data for trend analyses, collection of physical/chemical parameters on a weekly basis at the Tongue River station at Miles City and the Powder River station at Moorhead is recommended. If resources permit, the Rosebud Creek station at the mouth should also be sampled weekly. All other priority stations should collect physical/chemical data on a monthly basis to provide spatial distribution data. Sediment samples should be collected on a monthly basis, and biological samples on a seasonal or semiannual basis (except for monthly bacteriological analyses). Semiannual water samples for organic analyses are recommended.

In both the Tongue and Powder River Basins, water availability will be the major factor limiting future development of energy resources. However, until the Yellowstone Moratorium is ended and those water reservation requests that are pending are resolved, it is not known how much water is actually available for utilization or to what extent future users will impact the basins. Establishment of enforceable minimum instream flow requirements in both basins is recommended in light of the anticipated impact to fisheries and recreation activities during low water years as a result of increasing energy development.

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1. INTRODUCTION

This report is part of a multiagency study involving the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA) under various interagency agreements. The primary objective of this report series is to evaluate the existing water quality monitoring network in each study basin and to recommend needed modifications to the present sampling program design. As a basis for monitoring strategies recommended in this report, known energy developments, both present and planned, are defined, and available baseline data in the Tongue and Powder River Basins are examined. For assessment of these monitoring strategies, the impact of ongoing and anticipated energy development on both water quality and quantity in the western energy basins is considered. Future documents will present more detailed analyses of potential impacts from various energy technologies, sampling methodologies and frequency requirements, and site alternatives in light of updated information regarding water right allocations.

Throughout the 1950's, the United States was effectively energy self-sufficient, satisfying its needs with abundant reserves of domestic fuels, such as coal, oil and gas, and hydroelectric power. However, energy consumption has been increasing during the past 10 years at an annual rate of 4 to 5 percent, a per capita rate of consumption eight times that of the rest of the world (Federal Energy Administration, 1974). The Federal Energy Administration (1974) in the "Project Independence" report states that:

- By 1973, imports of crude oil and petroleum products accounted for 35 percent of total domestic consumption.
- Domestic coal production has not increased since 1943.
- Exploration for coal peaked in 1956, and domestic production of crude oil has been declining since 1970.
- Since 1968, natural gas consumption in the continental United States has been greater than discovery.

The United States now relies on oil for 46 percent of its energy needs, while coal, our most abundant domestic fossil fuel, serves only 18 percent of our total needs (U.S. Bureau of Reclamation, 1977). In light of the fact that we have only a few years remaining of proven oil and gas reserves, and to reduce our vulnerable dependency upon foreign oil, the Federal Government is promoting the development of untapped national energy resources in anticipation of upcoming energy requirements. Included among these resources are the abundant western energy reserves. Over half of the Nation's coal reserves are located in the Western United States, as well as effectively all of the uranium, oil shale, and geothermal reserves. Table 1 shows the projected national annual production levels for some recently expanding energy sources through the year 2000.

TABLE 1. SUMMARY OF TOTAL PROJECTED ANNUAL ENERGY PRODUCTION LEVELS FROM ADVANCED SOURCES (10^{15} joules per year)

Source	1970	1975	1980	1985	1990	1995	2000
Solar	0	0	0	400	2,500	4,000	12,000
Geothermal	1.8	14	72	180	360	720	1,400
Oil shale	0	0	610	2,000	2,700	3,400	4,000
Solid wastes	0	10	55	300	950	3,000	10,000
Total	1.8	24	737	2,880	6,510	11,120	27,400
U.S. demand	70,000	83,000	98,000	120,000	140,000	170,000	200,000
Percent of U.S. demand filled by above sources	$3x10^{-3}$	$3x10^{-2}$	0.8	2	5	6	13

Source: Modified from Hughes et al. (1974).

In the Tongue and Powder River Basins, energy resource development will primarily be the increased strip mining of coal with construction of associated coal gasification facilities, coal-fired powerplants, and transportation facilities. Development of uranium reserves, oil and gas fields, and other resources will occur but to a much lesser extent. It is difficult to assess the extent and severity of degradation in environmental quality that can be expected from this development. However, one of the biggest impacts will undoubtedly result from competition for water resources created by growing demands of municipal, industrial, agricultural, and reclamation projects. Energy development, which requires large amounts of water during extraction, transport, and conversion of resources to a usable form, can potentially have a great impact on water quality in the basin.

2. CONCLUSIONS

1. Surface water availability in the study area will be a factor limiting future growth and development patterns, including development of energy resources. However, it cannot be presently determined to what extent future users will impact the basins, since it is not known how much water is actually available for utilization or which water reservation requests filed during the Yellowstone Moratorium will be approved. It is expected that additional storage facilities must be created if water is to be available for anticipated developers. Transport of water from the Yellowstone River, as well as expanded use of regional ground-water resources, are other mechanisms expected to assume increasing importance in meeting projected industrial development in the Tongue and Powder River Basins.

2. Water quality throughout the Tongue and Powder River Basins is highly variable and strongly influenced by episodic high runoff and volumes of ground water found in the base flow of intermittent tributaries. Salinity and suspended sediment concentrations are already a problem in the Powder River, and a number of trace elements regularly exceed recommended criteria levels in the basins during high flow events. Existing water quality can be expected to further deteriorate as availability of water is reduced with increasing regional development. The parameters most likely affected by increased activities in the basins are salinity, elemental toxic substances, suspended sediment, nutrients, temperature, pH, alkalinity, and flow.

3. Agriculture, primarily irrigation, will continue to be the major consumer of water in the Tongue and Powder River Basins. Regional high salinity levels already largely restrict the variety of crops grown in the area, and increasing salinity, particularly in combination with reductions in flow, could have a major impact on this important user.

4. Point source discharge of pollutants from most energy development sites will most likely be localized and not pose a problem to overall water quality in the basins if discharge limitations are strictly enforced. Rather, nonpoint pollution from such sources as stack emissions, airborne dust, and subsurface drainage will be the major contributors. Runoff of effluents released from evaporation ponds to ground water or through overflow during storms poses an additional water quality threat, and regular monitoring for potential violation from energy development operation sites should be required.

5. Although point source discharges from traditional energy developments are not likely to pose water quality problems, the potential for direct contamination from in situ coal conversion activities is substantial. Organic

pollutants from this source are of special concern because of the lack of available data regarding both their nature and quantity.

6. Secondary development pollution impacts are likely to become a major contributing problem to water quality in the Tongue and Powder River Basins. Increases in organic pollutants and TDS levels from urban runoff and hydraulic modifications and pollution from the expanding use of water conditioners are expected.

7. In addition to the long-term trends, an increased number of pollution "episodes" (spills, etc.) are expected as a result of the increased transport of energy products in the area and the likelihood of flood runoffs from waste disposal, cooling systems, or mining sites. These brief but massive events could cause both short- and long-term effects that would be disastrous to both the ecology and the economy of the area.

8. The present U.S. Geological Survey (USGS) sampling network in the Tongue and Powder River Basins area is situated adequately for monitoring the impact of energy development in that area. Twenty-one USGS sampling stations have been selected as having the highest sampling priority throughout the basins examined in this report for energy monitoring efforts. Priorities have also been established for selection of water quality parameters necessary to monitor impacts from energy development in these rivers.

3. RECOMMENDATIONS

1. An expansion in the number of parameters regularly monitored to assess the impact of energy development on surface water quality in the Tongue and Powder River Basins is recommended. In particular, most trace elements and nutrients, which are presently collected only irregularly, should be incorporated into a more standardized sampling program. Pesticides, oils and greases, and organics such as phenols are other parameters that should be made part of a regular, if occasional, monitoring effort. Increased use of biological monitoring as a tool for measurement of long-term water quality trends is recommended.

2. The following water quality parameters are recommended for sampling to adequately assess energy resource development impact in the Tongue and Powder River Basins:

Total alkalinity
Total aluminum
Total ammonia
Total arsenic
Total beryllium
Bicarbonate
Biological oxygen demand of bottom sediments
Total boron
Total cadmium
Total organic carbon in bottom sediments
Dissolved calcium
Chloride
Total chromium
Specific conductance
Total copper
Total cyanide
Flow
Fluoride
Total iron
Total lead
Dissolved magnesium
Total manganese
Total mercury
Total molybdenum
Dissolved oxygen
Total nickel
Pesticides
Petroleum hydrocarbons
pH
Total phosphorus
Dissolved potassium
Total selenium
Dissolved sodium
Dissolved sulfate
Suspended sediments
Temperature
Total dissolved solids
Total zinc

3. The following U.S. Geological Survey stations are recommended to have the highest sampling priority in the Tongue and Powder River Basins study area for monitoring energy development impact on surface waters:

Sarpy Creek near Hysham, MT
East Fork Armells Creek near Colstrip, MT
Armells Creek near Forsyth, MT
Rosebud Creek above Pony Creek, MT
Rosebud Creek at mouth, near Rosebud, MT
Tongue River at Monarch, WY
Goose Creek below Sheridan, WY
Tongue River at State line near Decker, MT
Tongue River below Hanging Woman Creek, MT

Pumpkin Creek near Miles City, MT
Tongue River at Miles City, MT
Powder River near Kaycee, WY
Salt Creek near Sussex, WY
Powder River at Sussex, WY
Clear Creek near Arvada, WY
Powder River at Moorhead, MT
Mizpah Creek near Mizpah, MT
Powder River near Locate, MT
Yellowstone River at Forsyth, MT
Yellowstone River at Terry, MT
Powder River at mouth, MT

4. An improvement in uniformity of sampling at monitoring stations in the Tongue and Powder River Basins to allow temporal and spatial comparisons of accumulated data, particularly for the trace elements, is recommended. The Tongue River station at Miles City and the Powder River station at Moorhead should be sampled weekly in order to permit meaningful trend analyses. If resources permit, an additional station on Rosebud Creek at the mouth should also be sampled weekly. A station should be added on the Powder River at the mouth. This site, as well as the 18 other priority stations throughout the study area, should be monitored on a monthly basis to provide spatial distribution data.

5. Continued research to determine the nature and extent of pollution discharges from developing coal gasification and conversion sites is recommended, especially for those in situ project areas that will create many potentially harmful organic compounds. The exact nature and degree of escape of these compounds is presently unknown.

6. Establishment of enforceable minimum instream flow requirements in the Tongue and Powder River Basins is recommended in light of the anticipated impact to fisheries and recreational activities during low water years as a result of increasing energy development.

7. Salinity discharges from oil field operations in the Salt Creek watershed should be further evaluated and mitigation measures discussed. Consideration should be given to modification of permit discharge requirements for oil producers in the Salt Creek field. This would substantially reduce TDS loading to the Powder River drainage basin.

4. STUDY AREA

GEOGRAPHY

Location and Size

The Tongue and Powder River Basins (Figure 1) are located in a drainage area between the Big Horn Mountains on the southwest border and the Bear Lodge Mountains on the southeast side. The area's cornerstones include Hysham, Montana (NW); Terry, Montana (NE); 20 km north of Casper, Wyoming (SE); and the Rattlesnake Hills, 80 km west of Casper (SW).

Five drainage basins are included in the study area. These are: the Powder and Tongue Rivers, and the Sarpy, Armells, and Rosebud Creeks, all five of which flow northeasterly into the Yellowstone River (Figure 1). The Tongue and Powder are perennial rivers, which originate in the high mountains of Wyoming (Knapton and McKinley, 1977). Rosebud Creek, which originates a few miles north of the Wyoming-Montana State line, is also a perennial stream, which drains the eastern sides of the Wolf and Rosebud Mountains. Sarpy and Armells Creeks, which originate in the Little Wolf Mountains, are primarily intermittently flowing water bodies with some year-round flow near their respective confluence points with the Yellowstone River (Knapton and McKinley, 1977). The study area drains portions of 10 counties in the States of Wyoming and Montana and extends approximately 193 km east and west, between the communities of Hysham and Terry on the Yellowstone River, and 400 km north and south between the Yellowstone River and Casper, Wyoming. Table 2 shows the approximate drainage area and major inflowing tributaries to the five study basins.

The Tongue and Powder River Basins study area is approximately 72,000 km^2 and includes all or part of the following counties from north to south: Prairie, Custer, Rosebud, Carter, Powder River, and Big Horn Counties in Montana and Campbell, Sheridan, Johnson, and Natrona Counties in Wyoming.

The minimum elevation in the Tongue and Powder River drainages is 686 m near the confluence of the Powder and Yellowstone Rivers in Montana, and the maximum elevation is 4,012 m at the summit of Cloud Peak in the Big Horn Mountains of Wyoming (Missouri River Basin Commission, 1978b). In general, the Big Horn Mountains have a regional elevation ranging between 2,438 and 3,047 m. The mountains give way abruptly to a relatively narrow band of foothills that stand about 609 m above the plains. The Bear Lodge Mountains on the eastern side of the study area reach elevations of 2,028 m at Warren Peak, 1,500 m at Table Mountain, and 1,560 m at Devils Tower National Monument (Table 3) and supply water to the eastern portion of the study area drainages.

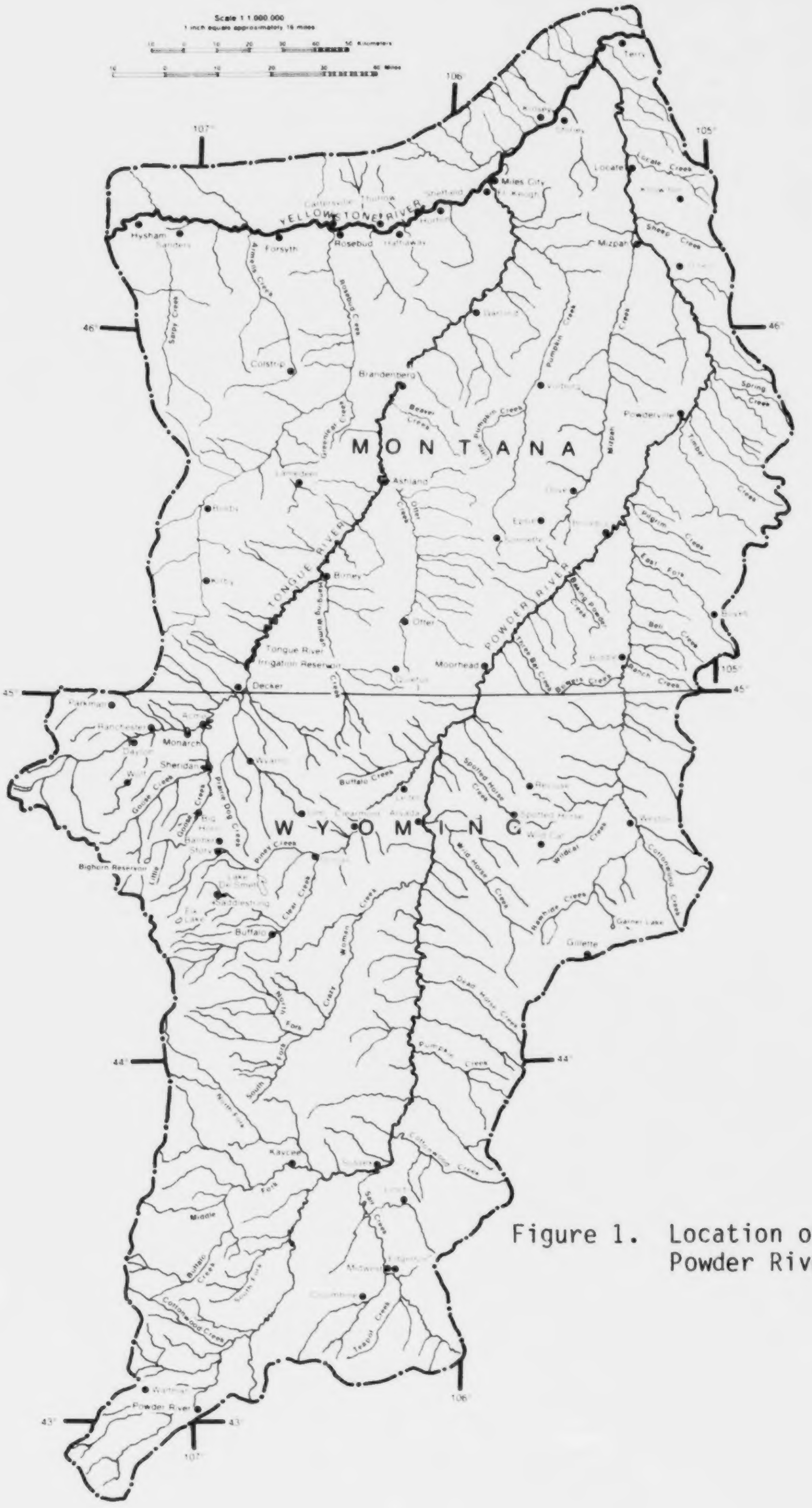

Scale 1:1,000,000
1 inch equals approximately 16 miles
Kilometers
Miles
107°
106°
105°
46°
45°
44°
43°
MONTANA
WYOMING
YELLOWSTONE RIVER
TONGUE RIVER
POWDER RIVER
Terry
Miles City
Fort Keogh
Locate
Mizpah
Hysham
Sanders
Forsyth
Rosebud
Hathaway
Sheffield
Colstrip
Brandenberg
Ashland
Birney
Otter
Powderville
Tongue River Irrigation Reservoir
Decker
Moorhead
Parkman
Ranchester
Dayton
Monarch
Sheridan
Big Horn
Bighorn Reservoir
Buffalo
Gillette
Kaycee
Midwest
Edgerton
Powder River
Sarpy Creek
Rosebud Creek
Pumpkin Creek
Mizpah Creek
Sheep Creek
Beaver Creek
Otter Creek
Hanging Woman Creek
Prairie Dog Creek
Goose Creek
Piney Creek
Clear Creek
Crazy Woman Creek
Buffalo Creek
Spotted Horse Creek
Wild Horse Creek
Wildcat Creek
Cottonwood Creek
Dead Horse Creek
Salt Creek
Teapot Creek
Buffalo Creek
Middle Fork
North Fork
South Fork
Spring Creek
Timber Creek
Little Powder River
Bitter Creek

Figure 1. Location of the Tongue and Powder River Basins.

TABLE 2. MAJOR TRIBUTARIES IMPACTING THE SARPY, ARMELLS, ROSEBUD, TONGUE, AND POWDER RIVERS

Mainstem	Total Drainage Area (km^2)	Major Tributaries
Sarpy Creek	1,173	Bear Creek, West Bear Creek, East Fork Sarpy Creek
Armells Creek	958	East and West Forks Armells Creek
Rosebud Creek	3,408	Muddy Creek, Lame Deer Creek, Greenleaf Creek, Sprague Creek
Tongue River	13,932	Hanging Woman Creek, Otter Creek, Pumpkin Creek, Goose Creek, North Fork Tongue River
Powder River	34,159	Clear Creek, Little Powder River, Mitzpah Creek, Crazy Woman Creek
Total	53,630	

Sources: Modified from U.S. Geological Survey (1976), Montana Department of Natural Resources and Conservation (1976c), and Knapton and McKinley (1977).

TABLE 3. MAJOR BUTTES AND MOUNTAINS CONTRIBUTING TO RUNOFF IN THE TONGUE AND POWDER RIVER BASINS

Butte or Mountain	State	Elevation (m)
Warren Peak	Wyoming	2,028
Table Mountain	Wyoming	1,500
Devils Tower National Monument	Wyoming	1,560
Pumpkin Butte	Wyoming	1,523
Liscom Butte	Montana	1,315
Wildhog Butte	Montana	1,243
Garfield Peak	Montana	1,315
Poker Jim Butte	Montana	1,243
Home Creek Butte	Montana	1,344
Badger Peak	Montana	1,348
Little Wolf Mountains	Montana	1,097
Fisher Butte	Montana	1,340

Climate

The Tongue and Powder River Basins have generally a semiarid climate that is typical of much of the Northern Great Plains Region (Montana Department of State Lands, 1977). The weather is characterized by cold winters, warm summers, and extreme annual and seasonal variations in temperature and precipitation (U.S. Geological Survey and Montana Department of State Lands, 1977). Elevations of a number of sites throughout the basins, as well as average annual rainfall and length of growing season are shown in Table 4.

Climate in this area of Montana is largely influenced by surrounding mountain ranges, particularly the Big Horn Mountains (U.S. Geological Survey and Montana Department of State Lands, 1977). During winter months, high

TABLE 4. CLIMATE VARIATIONS THROUGHOUT THE TONGUE AND POWDER RIVER BASINS, 1965-74

Station	Elevation (m)	Mean Length of Growing Season (days)	Mean Annual Precipitation (cm/yr)
Montana			
Biddle	1,096	117	37.1
Birney	968	111	35.6
Broadus	924	114	36.6
Busby	1,052	92	43.7
Colstrip	982	115	42.9
Forsyth	830	133	33.5
Miles City	801	140	40.6
Wyoming			
Arvada	1,122	116	33.8
Buffalo	1,416	107	34.5
Clearmont	1,236	100	37.6
Gillette 2E	1,389	120	42.4
Gillette 18SW	1,494	112	40.9
Kaycee	1,420	100	32.3
Leiter	1,280	126	38.4
Powder River	1,798	102	28.0
Sheridan	1,158	103	38.6

Source: Modified from Toy (1976).

pressure arctic air masses move south along the eastern side of the Canadian Rockies. These arctic storms usually deposit snow only in localized areas to the northern, northeastern, and eastern slopes of the mountain ranges. Frequently accompanying high winds produce characteristic blizzards and blowing snow throughout the area (U.S. Geological Survey, 1976). These severe cold winter spells are generally brief, and deep snow accumulation is uncommon because of thaws during periodic warm spells, which cause many intermittent streams to flow (Knapton and McKinley, 1977). Nevertheless, winters have been reported with snow buildup of 76 to 102 cm in the Colstrip area (Radian Corporation, 1976).

Spring and early summer in the area are the times of greatest annual precipitation. During this time the basins generally receive about 50 percent of their annual rainfall (Knapton and McKinley, 1977), with May and June having the highest monthly averages (U.S. Geological Survey, 1976). Most of this precipitation is from moisture-laden tropical air masses that are drawn northward from the Gulf of Mexico and produce summer thunderstorms. These storms are commonly accompanied by high winds and hail and result in localized flash flooding (U.S. Geological Survey and Montana Department of State Lands, 1977). Air masses moving eastward from the Pacific Ocean also contribute some summer rainfall to the region. Late summer typically consists of hot, dry days and cool nights, with diel temperature variations of as much as 4°C as a result of the low humidity and strong sunlight (U.S. Geological Survey and Montana Department of State Lands, 1977). Droughts are not uncommon, and in extreme years annual precipitation may fluctuate as much as 18 cm around the long-term average rainfall (U.S. Geological Survey, 1976). Net evaporation from lakes and reservoirs of the area is typically around 71 cm/yr (U.S. Geological Survey and Montana Department of State Lands, 1977).

Geology

The study area encompasses portions of the Big Horn Mountains, the structural Powder River Basin, and the Miles City Arch. Nearly all of the available energy resources in the area are to be found in the structural Powder River Basin (Figure 2). The Powder River structural basin is bounded on the south by the Laramie Range, on the east by the Black Hills, on the north by the Miles City Arch and other relatively small structural features, and on the west by the Big Horn Mountains (Wyoming Geological Association Technical Studies Committee, 1965). The structural basin is crossed by the present-day Tongue, Powder, Little Missouri, Belle Fourche, and Cheyenne Rivers.

Sedimentation in the area was controlled by regional tectonic features prior to Late Cretaceous time and records the advance and retreat of seas that extended areally over adjacent basins (Wyoming Geological Association Technical Studies Committee, 1965). These seas generally advanced from the north and the west resulting in thinner sediment layers in the eastern and southern portions of the basin. Diastrophic events in Late Cretaceous and early Tertiary time shaped the present-day Powder River structural basin. During the Paleocene the Black Hills, Laramie Range, and Big Horn Mountain uplifts began. By Eocene all the major features were delineated, and strong folding and faulting occurred. The flanking mountains were eroded and extensive coal swamps formed in the north and central basin. Renewed uplift in the Black Hills in Late Eocene time tilted the basin westward. A major regional uplift occurred at the close of Pliocene with extensive normal faulting. Erosion accelerated and streams became superimposed across present mountains. Erosion continued until the mountains were exhumed and basins reexcavated to their present relief.

Stratigraphy within the study area is relatively simple but is complicated by differing regional nomenclature. Figure 3 presents a generalized stratigraphic cross section from west to east across the structural basin. On the west flank of the basin the beds are folded upward and dip steeply to the

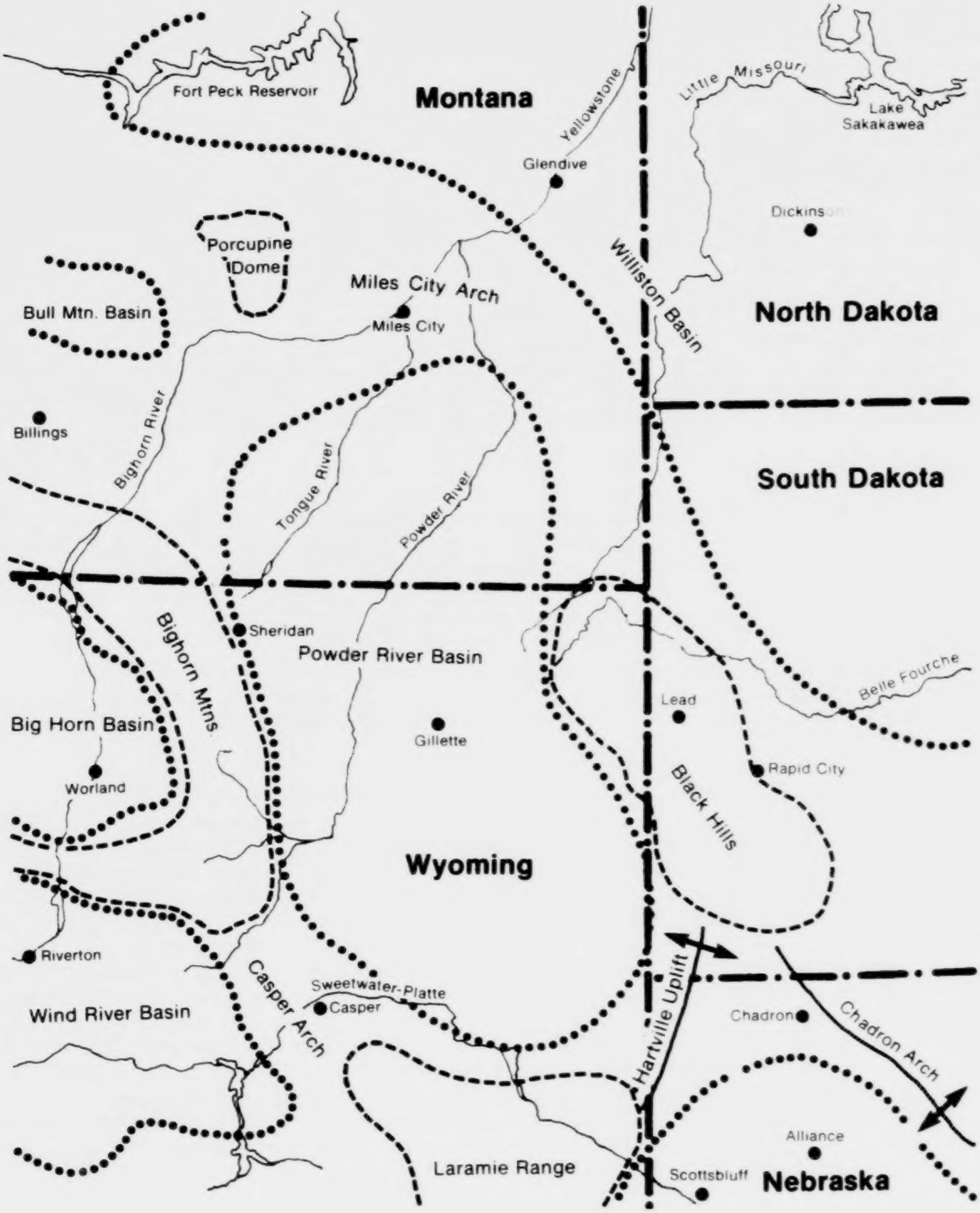

Fort Peck Reservoir
Montana
Yellowstone
Little Missouri
Lake Sakakawea
Glendive
Dickinson
Porcupine Dome
Williston Basin
Miles City Arch
Bull Mtn. Basin
Miles City
North Dakota
Billings
Bighorn River
South Dakota
Tongue River
Powder River
Sheridan
Powder River Basin
Bighorn Mtns
Belle Fourche
Lead
Big Horn Basin
Gillette
Black Hills
Rapid City
Worland
Wyoming
Riverton
Hartville Uplift
Casper Arch
Sweetwater-Platte
Casper
Wind River Basin
Chadron
Chadron Arch
Alliance
Laramie Range
Scottsbluff
Nebraska

Figure 2. The geologic structure of the Tongue and Powder River Basins.

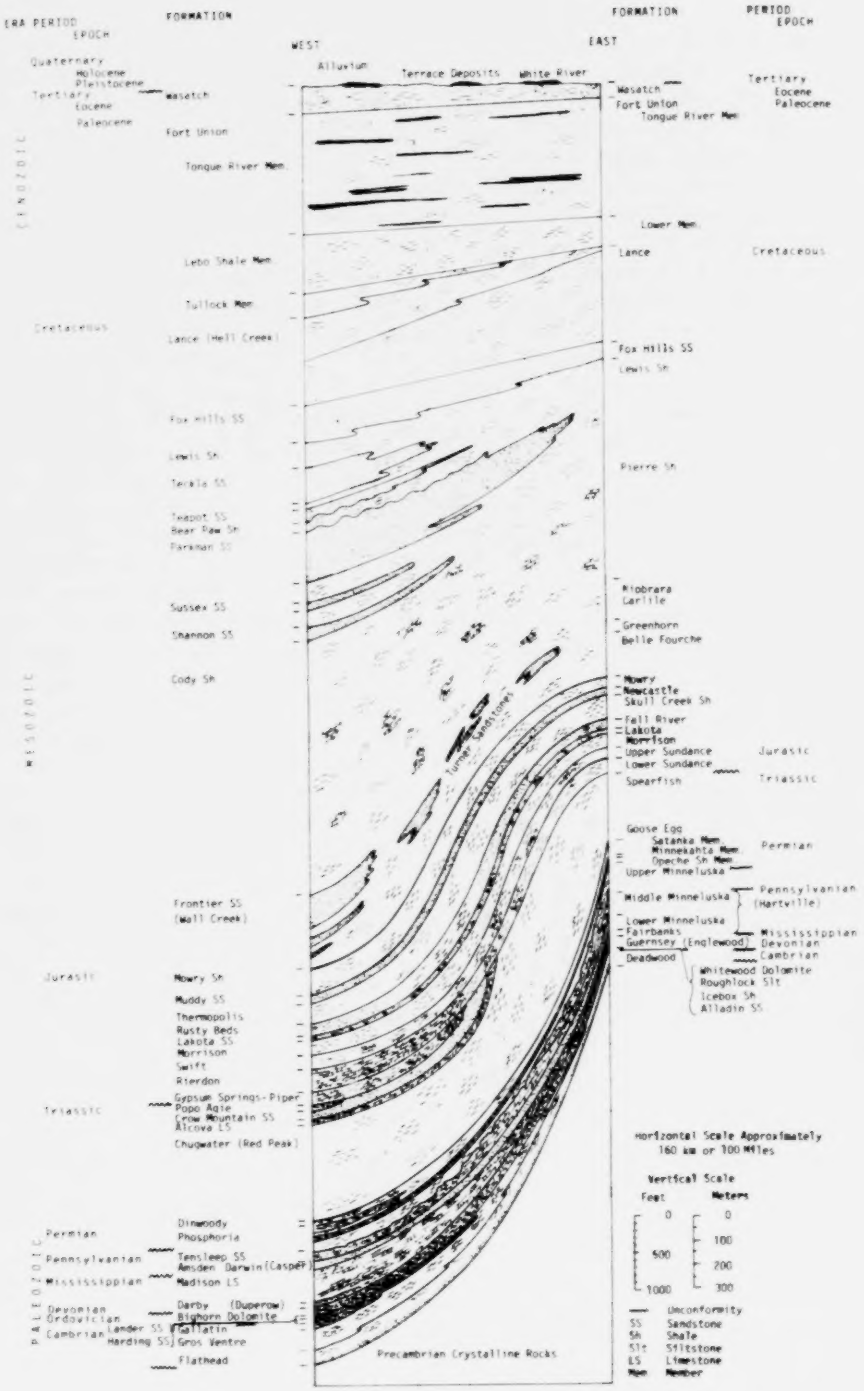

ERA PERIOD EPOCH
FORMATION
WEST
FORMATION
EAST
PERIOD EPOCH
Quaternary
Holocene
Pleistocene
Tertiary
Eocene
Paleocene
CENOZOIC
Alluvium
Terrace Deposits
White River
Wasatch
Fort Union
Tongue River Mem.
Wasatch
Fort Union
Tongue River Mem
Tertiary
Eocene
Paleocene
Lower Mem.
Lance
Cretaceous
Lebo Shale Mem.
Tullock Mem.
Cretaceous
Lance (Hell Creek)
Fox Hills SS
Lewis Sh
Fox Hills SS
Lewis Sh
Teckla SS
Pierre Sh
Teapot SS
Bear Paw Sh
Parkman SS
Niobrara
Carlile
Sussex SS
Shannon SS
Greenhorn
Belle Fourche
MESOZOIC
Cody Sh
Mowry
Newcastle
Skull Creek Sh
Turner Sandstones
Fall River
Lakota
Morrison
Upper Sundance
Lower Sundance
Jurasic
Spearfish
Triassic
Goose Egg
Satanka Mem.
Minnekahta Mem.
Opeche Sh Mem.
Permian
Upper Minneluska
Middle Minneluska
Pennsylvanian
(Hartville)
Frontier SS
(Wall Creek)
Lower Minneluska
Fairbanks
Guernsey (Englewood)
Mississippian
Devonian
Cambrian
Deadwood
Whitewood Dolomite
Roughlock Slt
Icebox Sh
Alladin SS
Jurasic
Mowry Sh
Muddy SS
Thermopolis
Rusty Beds
Lakota SS
Morrison
Swift
Rierdon
Gypsum Springs-Piper
Triassic
Popo Agie
Crow Mountain SS
Alcova LS
Chugwater (Red Peak)
Horizontal Scale Approximately
160 km or 100 Miles
Vertical Scale
Feet
Meters
0
500
1000
0
100
200
300
Permian
Dinwoody
Phosphoria
PALEOZOIC
Pennsylvanian
Tensleep SS
Amsden Darwin (Casper)
Mississippian
Madison LS
Devonian
Ordovician
Cambrian
Darby (Duperow)
Bighorn Dolomite
Lander SS
Harding SS
Gallatin
Gros Ventre
Flathead
Precambrian Crystalline Rocks
Unconformity
SS Sandstone
Sh Shale
Slt Siltstone
LS Limestone
Mem Member

Figure 3. Generalized geological stratigraphic sequence in the Powder River Basin.

east. Of particular economic interest are the Fort Union Formation, especially the Tongue River Member, which contains most of the coal reserves in the area, and the Montana Group, which has produced nearly half the oil from the State of Wyoming (Wyoming Geological Association Technical Studies Committee, 1965). Coal in the Tongue River Member of the Fort Union Formation exists in thick seams, some in excess of 10 meters. These are exposed or lie near the surface over much of the study area. The coal beds are generally extensive and can be traced for long distances, but varying thicknesses and different researches have resulted in confusing and overlapping nomenclature. Both the Tongue River Member and the overlying Wasatch Formation have been described in detail through a series of USGS Bulletins addressing area coal fields (Bryson and Bass, 1973). The location and publication number of each report is shown in Figure 4.

Generalized surface outcrops of the geologic formations are shown in Figure 5. Recent alluviums fill most stream valleys but have been omitted from the figure. Water quality is greatly affected by the geology of the aquifer and surface watershed exposures. Most of the surface exposures consist of interbedded siltstones, claystones, and sandstones with smaller amounts of carbonates and other evaporites. Hinkley and Ebens (1976) found quartz, kaolinite, and chlorite contents to vary significantly on a regional scale. Ebens and McNeal (1976), reporting on the geochemistry of the Fort Union Formation, note that in the shales (silt and claystones) most elemental variation occurs at local scales (25 km^2 cells) except for sodium, which showed regional variation. In sandstone, however, carbon, sodium, magnesium, and zinc all exhibited strong regional distributions. Feder and Saindon (1976) found that variation in ground-water chemical composition was on a large geographic scale. Dettman et al. (1976) noted the effect of area geology on water quality in the Tongue River-Goose Creek area. Knapton and McKinley (1977) described variation in water quality for area streams and ascribed many changes to areal geology (including ground-water discharges) noting that "downstream changes in major ions . . . were rather abrupt and appeared to correlate with changes in lithology." These effects are not unexpected since the dominant formations, the Wasatch, Fort Union, and Lance, were deposited in an environment of swampy flood plains, meandering streams, and coastal plains. These environments are characterized by rapidly changing sedimentary conditions and the deposition of intermixed lithofacies of sands, silts, clays, and organics. The chemical constituents of these relatively local deposits could be anticipated to vary significantly.

Population and Economy

The population of the Tongue and Powder River Basins is primarily distributed throughout a number of small rural communities. Although there exist some cities of substantial size, such as Miles City (9,023), Sheridan (10,856), and Gillette (7,194), the average population density for the area is only 0.4 persons per km^2 (Montana Department of Natural Resources and Conservation, 1976a). The smaller basin communities such as Forsyth and Decker rely heavily on supplies and services from nearby major population centers (U.S. Geological Survey and Montana Department of State Lands, 1977).

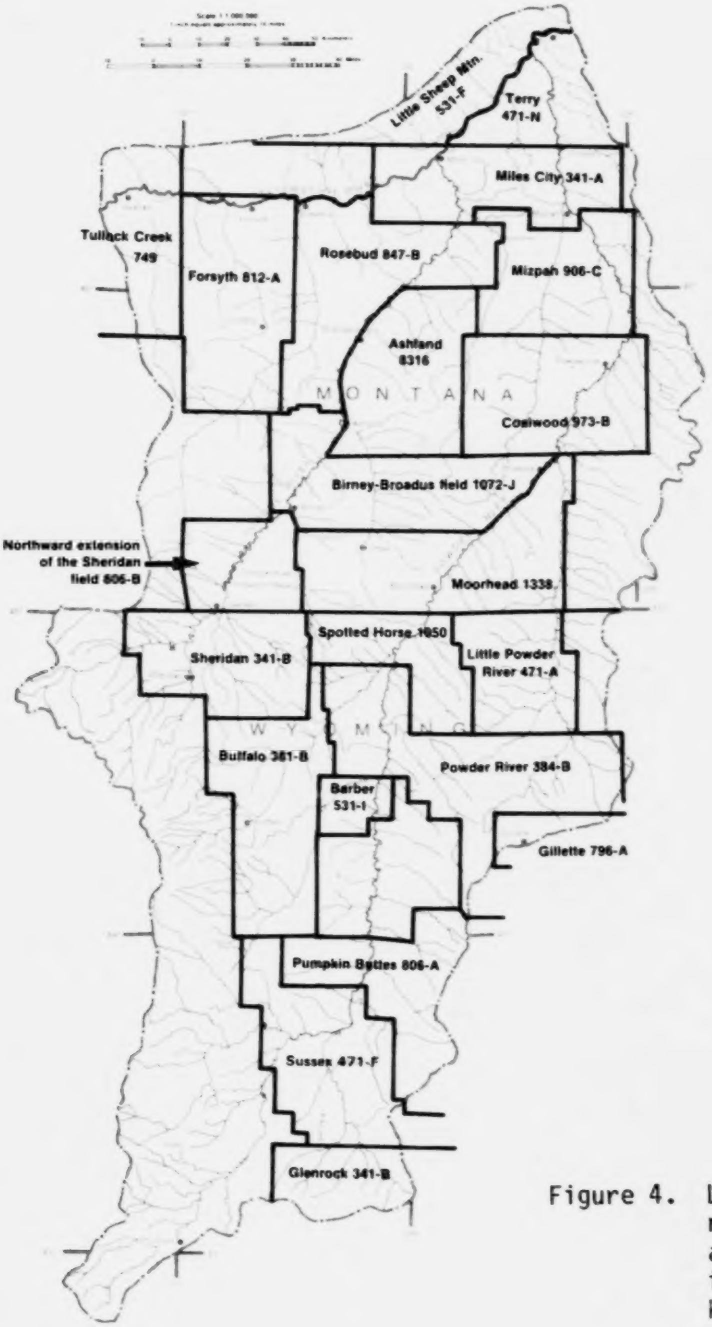
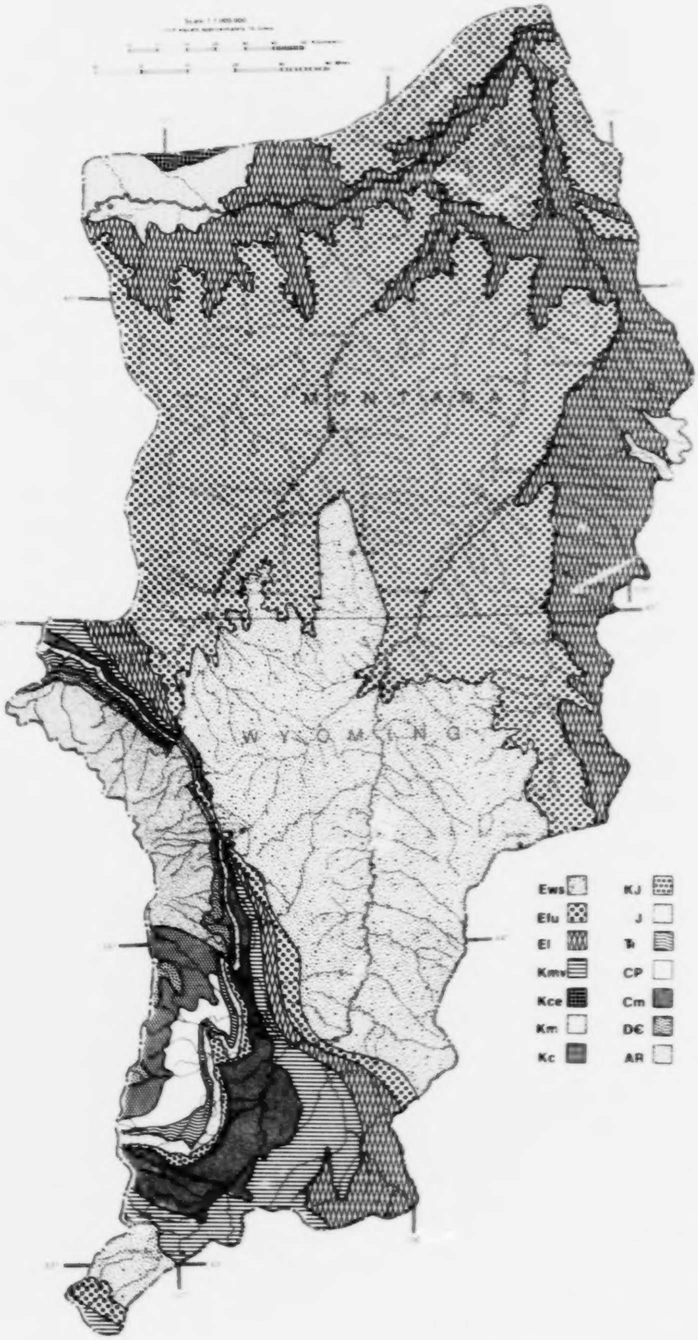

Little Sheep Mtn. 531-F
Terry 471-N
Miles City 341-A
Tullock Creek 749
Forsyth 812-A
Rosebud 847-B
Mizpah 906-C
Ashland 8316
MONTANA
Coalwood 973-B
Birney-Broadus field 1072-J
Northward extension of the Sheridan field 806-B
Moorhead 1338
Spotted Horse 1050
Sheridan 341-B
Little Powder River 471-A
WYOMING
Buffalo 381-B
Powder River 384-B
Barber 531-I
Gillette 796-A
Pumpkin Buttes 806-A
Sussex 471-F
Glenrock 341-B

Figure 4. Location and publication number of USGS bulletins addressing coal fields in the Tongue and Powder River Basins.


MONTANA
WYOMING
Ews
Efu
El
Kmv
Kce
Km
Kc
KJ
J
Tr
CP
Cm
D€
AR

Ews - Wasatch Formation
Efu - Fort Union Formation
El - Lance Formation
Kmv - Mesa Verde Group
Kce - Claggett and Eagle Formations
Km - Montana Group
Kc - Colorado Group
KJ - Morrison and Cloverly Formations
J - Sundance and Ellis Formations
Tr - Chugwater-Spearfish Formation
CP - Pennsylvanian Rocks
Cm - Mississippian Rocks
D€ - Devonian to Cambrian
AR - Archean Rocks

Figure 5. Generalized surface outcrops of the geologic formations in the Tongue and Powder River Basins.

Population in the Tongue and Powder River Basins fluctuates with changing economic trends. It is expected that mining will have a major influence on future populations, with increases of up to 40 percent by 1985 for Colstrip and Forsyth. Mining will bring jobs and influence the population to relocate from rural communities to urban centers, as well as encourage migration of mine workers from other States (Northern Great Plains Resource Program, 1974). In 1974, Rosebud County had shown an increase in population of 27.7 percent over five years. Sheridan and Big Horn Counties showed increases of 8.1 percent and 4.4 percent, respectively (U.S. Geological Survey and Montana Department of State Lands, 1977). Population growth is expected to continue in Big Horn, Powder River, and Rosebud Counties, the primary coal mining areas, over the next 20 years (Table 5).

TABLE 5. PREDICTED REGIONAL POPULATIONS FOR BIG HORN, POWDER RIVER, AND ROSEBUD COUNTIES, MONTANA, AND CAMPBELL COUNTY, WYOMING*

Year	Big Horn, Powder River, and Rosebud Counties, Montana	Campbell County, Wyoming
1980	11,600	14,200
1985	53,400	25,000
1990	74,800	32,200
2000	215,100	81,100

*Based on population projections after 1975 assuming nominal case population development.

Source: Modified from University of Oklahoma and Radian Corporation (1977b).

The Indian population in the study area is of economic significance since many of the mining and agricultural jobs throughout the region are held by Indians (University of Oklahoma and Radian Corporation, 1977b). In Big Horn and Rosebud Counties, Indians comprise, respectively, 38.9 percent and 30.2 percent of the total populations (U.S. Geological Survey and Montana Department of State Lands, 1977). Populations on the Crow Reservation have risen from 3,678 in 1963 to 4,334 in 1973, representing a 17.8 percent increase. The Cheyenne population has increased from 2,166 to 2,926, a 35.1 percent increase over the same time period.

The distribution of occupations in Rosebud and Campbell Counties is shown in Tables 6 and 7. In Rosebud County, agriculture is second only to community services, which is a grouping of several urban occupations (U.S. Geological Survey, 1974). It is noteworthy that in the later occupational data available for Campbell County, both mining and construction have jumped considerably; this trend in Campbell County could well represent the future for Rosebud and Big Horn Counties as well.

TABLE 6. OCCUPATIONAL DISTRIBUTION FOR ROSEBUD COUNTY, MONTANA, 1970

Occupation	Percent of Total Working Population
Agriculture	22.8
Mining	2.8
Construction	5.2
Manufacturing	7.8
Railroads	4.5
Other transportation	0.3
Communication	0.4
Community services	38.9
Welfare, religious, and nonprofit organizations	9.3
Public administration	8.0

Source: Modified from U.S. Geological Survey (1974).

TABLE 7. OCCUPATIONAL DISTRIBUTION FOR CAMPBELL COUNTY, WYOMING, 1975

Occupation	Percent of Total Working Population
Agriculture	8.4
Mining	20.3
Construction	23.1
Manufacturing	2.4
Transportation	6.6
Communication and utilities	2.5
Financial, insurance, and real estate	3.0
Community services	16.6
Retail trade	13.0
Public administration	1.8
Wholesale trade	2.3

Source: Modified from University of Oklahoma and Radian Corporation (1977b).

Land Ownership and Usage

The greatest percentage of land in the Tongue and Powder River Basins is privately owned (Table 8). There are two Indian reservations in the study area, the Northern Cheyenne Indian Reservation (1,758 km^2) and the Crow Indian Reservation (6,321 km^2). The former borders on the Tongue River (Figure 6) and includes much of Rosebud Creek (Northern Great Plains Resource Program, 1975).

The Tongue River Basin is approximately one-third (1,259 km^2) National forest land. It originates in the Bighorn National Forest and, further downstream, borders the Custer National Forest. Portions of the mainstem Powder River, Clear Creek, and Crazy Woman Creek flow through National forest land; however, the basin is predominately privately owned with sections of Bureau of Land Management (BLM) land. Much of the upland forested areas are

TABLE 8. THE DISTRIBUTION OF LAND OWNERSHIP IN YELLOWSTONE, BIG HORN, ROSEBUD, CUSTER, AND POWDER RIVER COUNTIES, 1972

County	Percent of County Land			
	Private	Federal	State	Indian
Yellowstone	82	5	4	9
Big Horn	34	14	3	49
Rosebud	67	11	6	7
Powder River	63	28	9	0
Custer	77	17	6	0

Source: Modified from Montana Department of Natural Resources and Conservation (1976a).

set aside for recreation, grazing, and limited timber production (Northern Great Plains Resource Program, 1974).

Approximately 90 percent of the land use in Big Horn and Rosebud Counties, Montana, and Sheridan County, Wyoming, is agricultural. Most of this land is used for grazing; however, small grains and alfalfa are grown on about 5 percent of the total land used for agriculture. The nonagricultural land is composed of residential areas, streams, and water bodies (U.S. Geological Survey and Montana Department of State Lands, 1977).

Mining represents approximately 3.5 percent of the land use in Montana and is on land leased from both private and Indian owners. As industry increases in the Tongue and Powder River Basins, so will the need for land. Within Big Horn, Powder River, and Rosebud Counties, it is estimated that a total of 6,340 km^2 will be needed by the year 2000 for energy facilities (University of Oklahoma and Radian Corporation, 1977b). This represents 18.3 percent of the total land in these three counties. Urban demands will increase to 150.6 km^2, or 0.4 percent of the total land available in these three counties by the year 2000 (Tables 9 and 10). Land requirements for energy development in Campbell County are projected to increase to 1,509 km^2 or 12.2 percent of the total land available, with urban development demands increasing to 0.5 percent of the total (University of Oklahoma and Radian Corporation, 1977b).

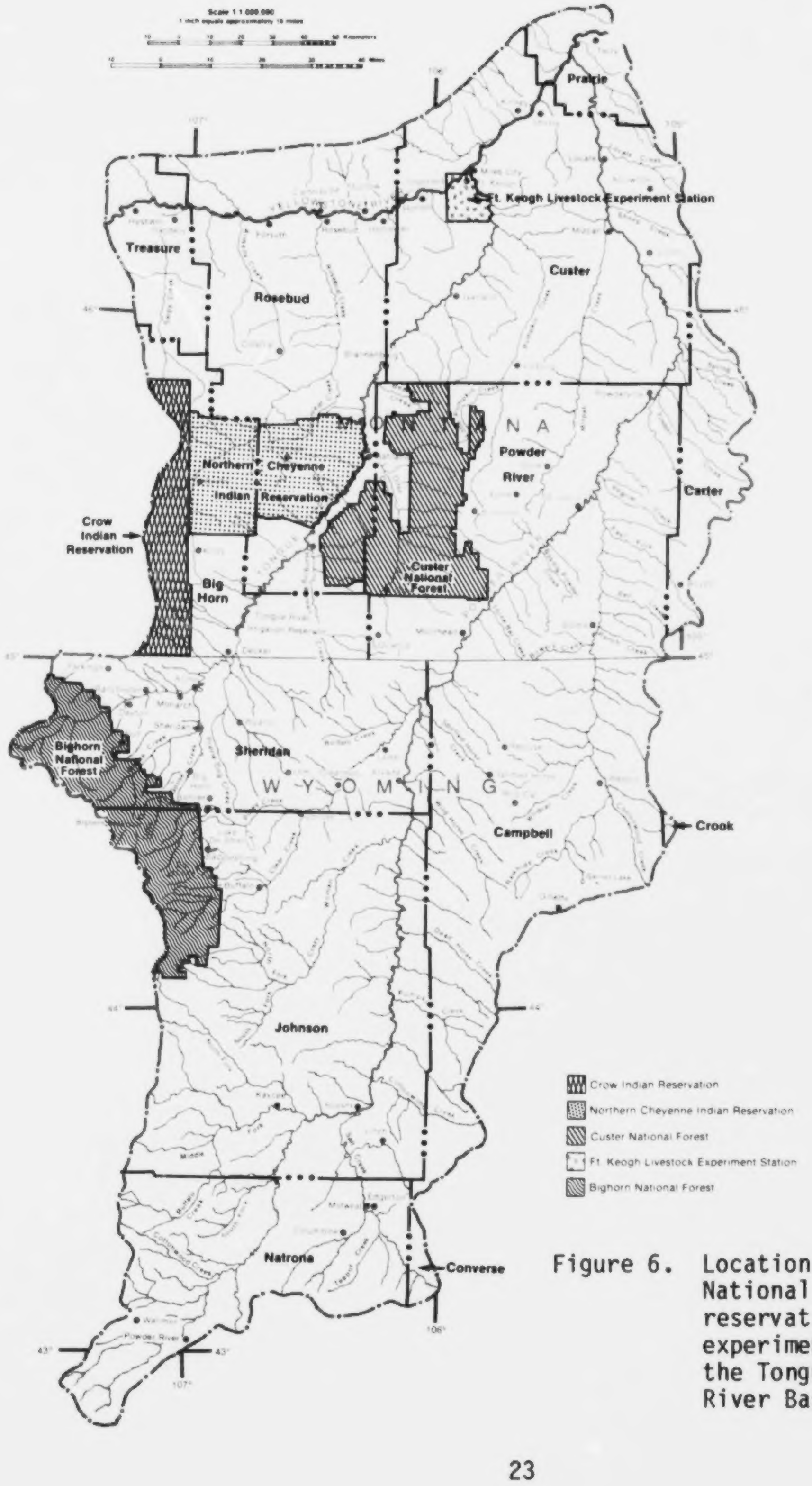

Prairie
Ft. Keogh Livestock Experiment Station
Treasure
Custer
Rosebud
MONTANA
Northern Cheyenne Indian Reservation
Powder River
Carter
Crow Indian Reservation
Custer National Forest
Big Horn
Bighorn National Forest
Sheridan
WYOMING
Campbell
Crook
Johnson
Natrona
Converse
Crow Indian Reservation
Northern Cheyenne Indian Reservation
Custer National Forest
Ft. Keogh Livestock Experiment Station
Bighorn National Forest
107°
106°
105°
46°
45°
44°
43°

Figure 6. Location of counties, National forests, Indian reservations, and experimental stations in the Tongue and Powder River Basins.

TABLE 9. PROJECTED LAND USE IN BIG HORN, POWDER RIVER, AND ROSEBUD COUNTIES, MONTANA, FOR ENERGY FACILITIES AND URBAN DEVELOPMENT THROUGH THE YEAR 2000*

Year	Energy Facilities		Urban Development		Combined Use	
	(km^2)	(% of total)	(km^2)	(% of total)	(km^2)	(% of total)
1980	505	1.46	8	0.02	513	1.48
1985	1,981	5.73	37	0.11	2,018	5.84
1990	2,722	7.88	52	0.15	2,774	8.03
2000	6,341	18.34	151	0.44	6,462	18.78

Total land available: 34,572 km^2

*Based on nominal case development projections.

Source: Modified from University of Oklahoma and Radian Corporation (1977b).

TABLE 10. PROJECTED LAND USE IN CAMPBELL COUNTY, WYOMING, FOR ENERGY FACILITIES AND URBAN DEVELOPMENT THROUGH THE YEAR 2000*

Year	Energy Facilities		Urban Development		Combined Use	
	(km^2)	(% of total)	(km^2)	(% of total)	(km^2)	(% of total)
1980	698	5.66	10	0.08	708	5.74
1985	910	7.39	18	0.14	928	7.53
1990	1,193	9.69	22	0.18	1,215	9.87
2000	1,509	12.25	57	0.46	1,566	12.71

Total land available: 12,318 km^2

*Based on nominal case development projections.

Source: Modified from University of Oklahoma and Radian Corporation (1977b).

WATER RESOURCES

Lotic

The Tongue River originates on the eastern slopes of the Big Horn Mountains in Wyoming and flows from its headwaters in the southeastern edges of the Big Horn Mountains in Wyoming to its confluence with the Yellowstone River in Montana. The Tongue River provides approximately 3.4 percent and the Powder River 4.9 percent of the total flow in the Yellowstone River at their respective points of confluence (Knapton and McKinley, 1977).

Clear Creek and Crazy Woman Creek, major perennial tributaries to the Powder River (Table 2), as well as the North Fork Tongue River and Goose Creek, perennial drainages in the Tongue River Basin, originate in Wyoming. Mountain snowpack melt in the Big Horn Mountains produces spring flooding and maintains flow in these tributaries to the Powder and Tongue Rivers throughout the summer months. The Little Powder River receives its reserves from the Black Hills area and Thunder Basin drainage in Wyoming. The remaining major streams flowing into the Powder and Tongue originate in Montana and are primarily fed by snowmelt from the Rosebud and Little Wolf Mountains and by precipitation. Many of these streams are intermittent; it is estimated that only 3 percent of the precipitation that falls into the area leaves as streamflow (U.S. Geological Survey, 1976).

Lentic

Although there are more than 1,500 natural lakes in Montana, and over 60 reservoirs having storage capacities greater than 6.2 million m^3, the majority of these water bodies are located in the western and south-central portions of the State (Montana Department of Natural Resources and Conservation, 1976c). In the Tongue-Powder River study area, there are only two lentic water bodies of any size: the Tongue River Reservoir (surface area 14.2 km^2) (U.S. Environmental Protection Agency, 1977c) and Lake de Smet in the Powder River drainage (surface area 10.7 km^2) (U.S. Environmental Protection Agency, 1977b). Farm and stock ponds provide a significant amount of additional water storage in the two basins, and a great many small mountain lakes exist in the upper elevations of Wyoming that feed tributaries to the basins (Montana Department of Natural Resources and Conservation, 1976c). There are three small storage reservoirs in Wyoming that somewhat regulate flow in the upper Powder River (Missouri River Basin Commission, 1978b).

There are a number of plans underway to provide additional storage on major tributaries throughout the Yellowstone River Basin to help meet increasing demands, particularly industrial, for water supplies. Three new reservoirs have been proposed for the Powder River, and two new reservoirs suggested for tributaries flowing south into the Yellowstone River between the communities of Hysham and Miles City (Table 11). Construction of a new Tongue River Dam 6 km downstream of the existing facility has also been proposed.

TABLE 11. NEW RESERVOIRS PROPOSED FOR FUTURE DEVELOPMENT IN THE POWDER AND TONGUE RIVER BASINS, MONTANA AND WYOMING

Reservoir Name	Location	Anticipated Firm Annual Yield ($m^3 \times 10^6$)	Purpose
Moorhead Reservoir	Powder River, astride the Montana-Wyoming State line	133.217 (70.309 - MT, 62.908 - WY)	Industrial
Hole-in-the-Wall Reservoir	Middle Fork Powder River, WY	24.670	Industrial, irrigation
Box Elder Reservoir	Offstream reservoir using Clear and Piney Creeks, WY for water source	37.005	Industrial, private
Cedar Ridge Reservoir	Starved-to-Death Creek, MT	148.019	Offstream storage of flows of the Yellowstone River
New Tongue River Reservoir	6.3 km downstream from existing dam or at confluence of Tongue River with Fourmile Creek	123.349	Industrial, irrigation

Sources: Modified from U.S. Bureau of Reclamation (1972) and U.S. Geological Survey and Montana Department of State Lands (1977).

Ground Water

Most of the water used for municipal and industrial purposes in the study basins is supplied by the ground-water resources in Montana and Wyoming. Aquifers in the coal beds, particularly in the Tongue River Member, are the most extensive in use and the most predictable sources of ground water (U.S. Geological Survey and Montana Department of State Lands, 1977). Generally, these aquifers are under artesian pressure and sufficiently permeable to yield adequate amounts of water for domestic and stock use. Sandstone aquifers in the Tongue River Member occur as discontinuous lenses in the otherwise less permeable material that forms the overburden and interburden above and below the coal beds (U.S. Geological Survey and Montana Department of State Lands, 1977). These sandstone aquifers are little used since they are of limited areal extent and their wells do not yield long-term or dependable supplies. Alluvium in some regions is a productive aquifer along streams and rivers where the sand, silt, and clay has not cemented or consolidated (Montana Department of Natural Resources and Conservation, 1976c). In the Decker area, water from surface runoff or precipitation enters the highly permeable clinker and settles in a zone of saturation, which becomes another additional source of ground-water supplies. Siltstone, mudstone, and shale are relatively impermeable, and wells drifted in these rocks generally yield little or no water.

It is believed that deep ground-water resources are even more extensive in the Missouri River Basin than reserves in shallow aquifers, although quantitative estimates are not available (Lord et al., 1975). Potential ground-water supplies exist in the deeper aquifers such as the Fox Hills aquifer and Madison limestone; however, at present there are no plans to commercially develop ground water from these deep sources.

Ground-water supplies are largely recharged by precipitation. In the Sarpy Creek region, approximately 63 percent of the net area precipitation is leached into the soil to ground water, and 37 percent ends up as streamflows (U.S. Geological Survey, 1976). Ground-water recharge is reduced during the growing season when surface flows are less and evaporation and transpiration demands by vegetation take up much of the precipitation moisture from the soil (U.S. Geological Survey, 1976). During the summer months, precipitation and snowmelt runoff are reduced and natural ground-water discharge becomes the only source of flow for many of the tributaries of the study area (Knapton and McKinley, 1977). The Tongue River Reservoir represents a low point, or sink, into which shallow ground-water aquifers also discharge; the rate of discharge is dependent on water surface elevation of the reservoir.

Ground water is primarily used for livestock and industrial purposes; in the Sarpy Creek area, livestock accounts for 90 percent of the ground-water consumption (U.S. Geological Survey, 1976). The rural, public supply, and irrigational demands for water in Montana and Wyoming (0.09, 0.21, and 0.34 million m^3/day, respectively) place a significant strain on ground-water supplies in those areas in which surface water is not available or would have to be imported (McGuinness, 1963). Ground water used for these purposes, however, generally must be supplemented with surface flow since it is commonly heavily mineralized and unacceptable for most uses directly.

Ground water is expected to assume an increasingly important role in industrial development and water needs in Montana and Wyoming (McGuinness, 1963). However, in the Tongue and Powder River Basin areas, the U.S. Bureau of Reclamation (1972) reports "development of ground-water resources will not produce an adequate water supply for industrial needs of the size anticipated." The scarcity of these ground-water resources may become acute in areas in which rainfall does not produce sufficient runoff for immediate use or creation of storage facilities and does not regenerate the existing aquifers.

WATER USES

The unspoiled surface water resources in the arid Tongue and Powder River watersheds serve a variety of needs. Perennial streams in the basins, as well as the Tongue River Reservoir, provide water for such uses as municipal water supplies, irrigation, recreational activities (including fishing and other sports), industrial needs, livestock watering, governmental uses (fisheries and State water), and limited generation of electricity.

FISH AND WILDLIFE RESOURCES

The Tongue and Powder River drainage areas support a variety of fish and wildlife. These study areas are comprised of four major biotopes, or habitat types, in which the species compositions directly or indirectly reflect the local economy and environment.

The grassland biotope is characterized by open grasslands with varying amounts of sagebrush and other shrubs. Some of these characteristic grasses include: green needlegrass, Sandberg bluegrass, and prairie junegrass. This biotope is located at lower elevations in the rolling valleys of the badlands near the Tongue River; 80 to 90 percent of the basin areas suitable for strip mining are in this biotope (U.S. Geological Survey, 1974). Mammals in the area include the pronghorn antelope (Antilocapra americana), whitetail jackrabbit (Lepus townsendii), and prairie vole (Microtus ochrogaster). The avian population includes the western meadowlark (Sturnella neglecta), horned lark (Eremophila alpestris), Brewer's sparrow (Spizella breweri), and others (Table 12). This biotope is of great economic interest as a key area of competition for grazing between livestock and naturally occurring species (Radian Corporation, 1976). Other important human impacts to this habitat include agricultural cultivation and sagebrush eradication. Expansions in cultivation result in a new habitat that may, as a result of increased water availability and niche space, introduce new species. However, the cultivation of land may abolish other species or create physical barriers that restrict the population to unfavorable habitat. Figure 7 illustrates that to maintain wildlife diversity requires a preservation of mixed habitats. The species limited to the exterior of the figure represent those species most vulnerable to extinction via elimination of habitat. An example of this is the process of sagebrush eradication, which will affect the population of resident wildlife such as the sage grouse but will allow native grassland species to move into the area.

TABLE 12. THE CHARACTERISTIC FAUNA OF THE GRASSLAND BIOTOPE IN THE TONGUE AND POWDER RIVER BASINS

	Common Name	Scientific Name
Mammals		
	Pronghorn antelope	Antilocapra americana
	Whitetail jackrabbit	Lepus townsendii
	Ord kangaroo rat	Dipodomys ordii
	Western harvest mouse	Reithrodontomys megalotis
	Least chipmunk	Eutamias minimus
	Badger	Taxidea taxus
	Prairie vole	Microtus ochrogaster
Birds		
	Western meadowlark	Sturnella neglecta
	Horned lark	Eremophila alpestris
	Brewer's sparrow	Spizella breweri
	Sage grouse	Centrocercus urophasianus
	Prairie falcon	Falco mexicanus
Reptiles and amphibians		
	Plains spadefoot toad	Scaphiopus bombifrons
	Prairie rattlesnake	Crotalus viridis
	Western hognose snake	Heterodon nasicus
	Gopher snake	Pituophis melanoleucus
	Short-horned lizard	Phrynosoma douglassi

Sources: Modified from U.S. Geological Survey (1974) and Radian Corporation (1976).

The ponderosa pine biotope is characterized by broken upland mesas and buttes where rainfall is more abundant than at the lower elevations. It is often a dense forest of moderately large pines and junipers with interspersed grasses and shrubs and is generally located above those areas to be mined. The biotope is occupied predominately by mule deer (Odocoileus hemionus), porcupine (Erethizon dorsatum), and bobcat (Lynx rufus). The avian population includes sharp-tailed grouse (Pedioecetes phasianellus), wild turkey (Meleagris gallopavo), and others (Table 13). This area is environmentally affected least of all the biotopes by mining operations and human activities.

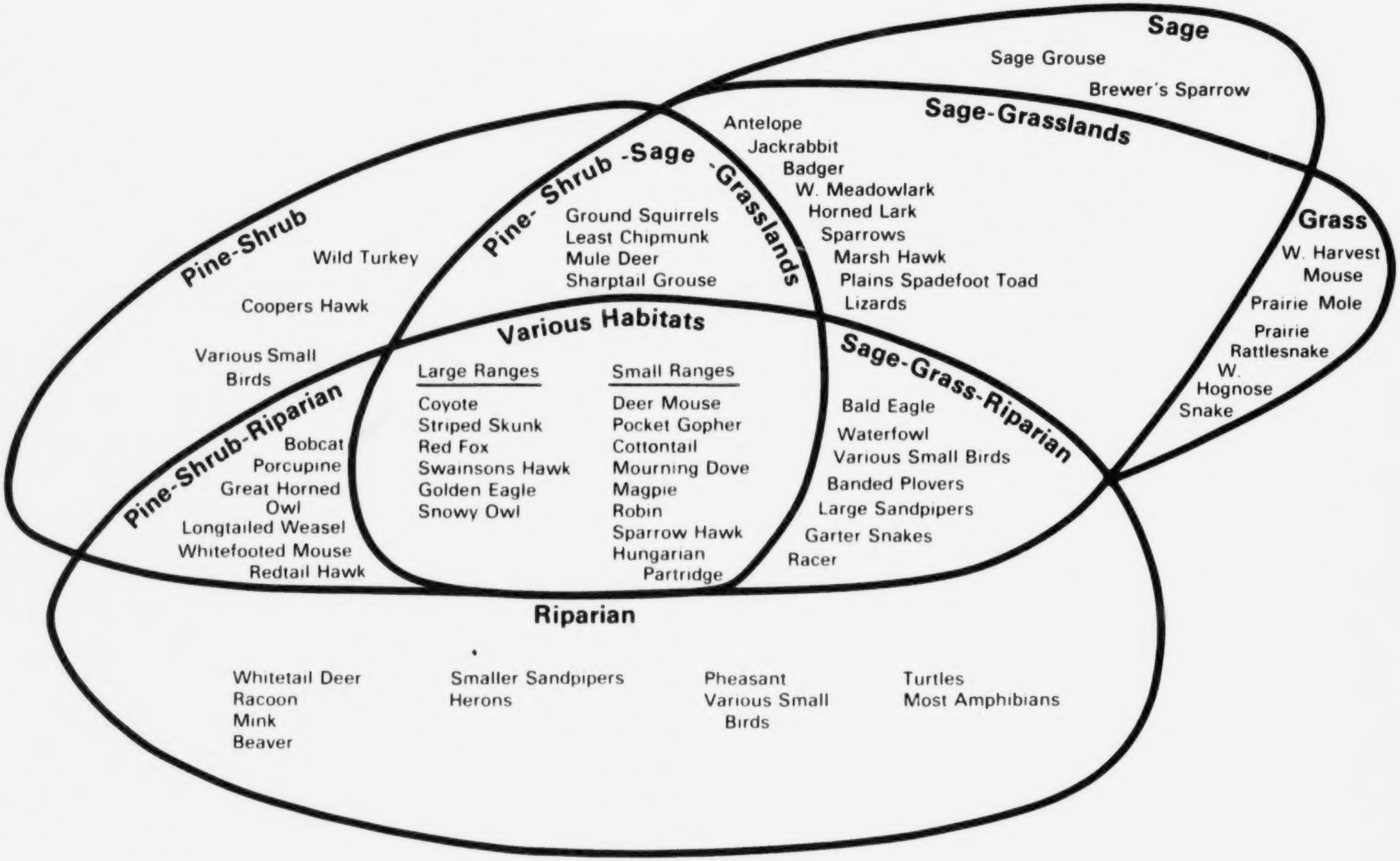

Sage
Sage Grouse
Brewer's Sparrow
Sage-Grasslands
Antelope
Jackrabbit
Badger
W. Meadowlark
Horned Lark
Sparrows
Marsh Hawk
Plains Spadefoot Toad
Lizards
Grass
W. Harvest Mouse
Prairie Mole
Prairie Rattlesnake
W. Hognose Snake
Pine-Shrub
Wild Turkey
Coopers Hawk
Various Small Birds
Pine- Shrub -Sage -Grasslands
Ground Squirrels
Least Chipmunk
Mule Deer
Sharptail Grouse
Various Habitats
Large Ranges
Coyote
Striped Skunk
Red Fox
Swainsons Hawk
Golden Eagle
Snowy Owl
Small Ranges
Deer Mouse
Pocket Gopher
Cottontail
Mourning Dove
Magpie
Robin
Sparrow Hawk
Hungarian Partridge
Sage-Grass-Riparian
Bald Eagle
Waterfowl
Various Small Birds
Banded Plovers
Large Sandpipers
Garter Snakes
Racer
Pine-Shrub-Riparian
Bobcat
Porcupine
Great Horned Owl
Longtailed Weasel
Whitefooted Mouse
Redtail Hawk
Riparian
Whitetail Deer
Racoon
Mink
Beaver
Smaller Sandpipers
Herons
Pheasant
Various Small Birds
Turtles
Most Amphibians

Figure 7. Distribution of wildlife with respect to habitat near Colstrip, Montana.

TABLE 13. THE CHARACTERISTIC FAUNA OF THE PONDEROSA BIOTOPE IN THE TONGUE AND POWDER RIVER BASINS

	Common Name	Scientific Name
Mammals		
	Mule deer	*Odocoileus hemionus*
	Porcupine	*Erethizon dorsatum*
	Bobcat	*Lynx rufus*
	White-footed mouse	*Peromyscus sp.*
	Longtail weasel	*Mustela frenata*
	Thirteen-lined ground squirrel	*Spermophillus tridecemlineatus*
Birds		
	Great horned owl	*Bubo virginianus*
	Cooper's hawk	*Accipiter cooperii*
	Red-tailed hawk	*Buteo jamaicensis*
	Red-shafted flicker	*Colaptes cafer*
	Black-capped chickadee	*Parus atricapillus*
	Mountain bluebird	*Sialia currucoides*
	Hairy woodpecker	*Dendrocopos villosus*
	Wild turkey	*Meleagris gallopavo*
	Sharp-tailed grouse	*Pedioecetes phasianellus*

Sources: Modified from U.S. Geological Survey (1974) and Radian Corporation (1976).

The riparian biotope is the most fragile of the four. It is comprised of narrow thickets of trees (cottonwoods, ash, box elders, and willows) and shrubs along small streams that broaden into a more forest-like character in the larger flood plains. Human activities such as agriculture and water diversion have altered many of these natural systems. The vegetation and animals of the riparian biotope are greatly affected by changes in neighboring areas. Increased annual rainfall in the ponderosa biotope may effect an increase in water availability and may result in creation of more riparian habitats. The riparian habitat, although the least extensive, is perhaps the key element in regional ecosystem stability. The predominant mammalian species include whitetail deer (*Odocoileus virginianus*), raccoon (*Procyon lotor*), and beaver (*Castor canadensis*). The avian population consists of waterfowl such as the mallard (*Anas platyrhynchos*), Canada goose (*Branta canadensis*), and great blue heron (*Ardea herodias*). Other characteristic riparian avian species include the barn swallow (*Hirundo rustica*) and ring-necked pheasant (*Phasianus colchicus*) (Table 14).

TABLE 14. THE CHARACTERISTIC FAUNA OF THE RIPARIAN BIOTOPE IN THE TONGUE AND POWDER RIVER BASINS

	Common Name	Scientific Name
Mammals		
	Whitetail deer	Odocoileus virginianus
	Raccoon	Procyon lotor
	Little brown bat	Myotis lucifugus
	Mink	Mustela vison
	Beaver	Castor canadensis
	Red fox	Vulpes fulva
Birds		
	Bald eagle	Haliaeetus leucocephalus
	Mallard	Anas platyrhynchos
	Canada goose	Branta canadensis
	Greater yellowlegs	Tringa melanoleuca
	Killdeer	Charadrius vociferus
	Great blue heron	Ardea herodias
	Barn swallow	Hirundo rustica
	Red-winged blackbird	Agelaius phoeniceus
	Loggerhead shrike	Lanius ludovicianus
	Western kingbird	Tyrannus verticalis
	Yellowthroat	Geothlypis trichas
	Red-shafted flicker	Colaptes cafer
	Ring-necked pheasant	Phasianus colchicus
Reptiles and Amphibians		
	Eastern yellow-bellied racer	Coluber constrictor
	Western garter snake	Thamnophis elegans
	Painted turtle	Chrysemys picta
	Leopard frog	Rana pipiens
	Boreal chorus frog	Pseudacris triseriata

Sources: Modified from U.S. Geological Survey (1974) and Radian Corporation (1976).

The aquatic biotope, found in all perennial streams of the study area, supports a variety of game fish such as northern pike (Esox lucius), walleye (Stizostedion vitreum vitreum), rainbow trout (Salmo gairdneri), and others (Table 15). However, the predominant species are not the game fish but rather

TABLE 15. FISH SPECIES KNOWN TO OCCUR IN THE TONGUE AND POWDER RIVER BASINS (including Sarpy and Rosebud Creeks)

Common Name		Scientific Name
Shovelnose sturgeon	-	*Scaphirhynchus platorynchus*
Paddlefish	-	*Polyodon spathula*
Goldeye	-	*Hiodon alosoides*
Mountain whitefish	-	*Prosopium williamsoni*
Rainbow trout	-	*Salmo gairdneri*
Brown trout	-	*Salmo trutta*
Brook trout	-	*Salvelinus fontinalis*
Northern pike	-	*Esox lucius*
Goldfish	-	*Carassius auratus*
Lake chub	-	*Couesius plumbeus*
Carp	-	*Cyprinus carpio*
Brassy minnow	-	*Hybognathus hankinsoni*
Silvery minnow	-	*Hybognathus nuchalis*
Plains minnow	-	*Hybognathus placitus*
Sturgeon chub	-	*Hybopsis gelida*
Flathead chub	-	*Hybopsis gracilis*
Golden shiner	-	*Notemigonus crysoleucas*
Emerald shiner	-	*Notropis atherinoides*
Sand shiner	-	*Notropis stramineus*
Fathead minnow	-	*Pimephales promelas*
Longnose dace	-	*Rhinichthys cataractae*
Creek chub	-	*Semotilus atromaculatus*
River carpsucker	-	*Carpiodes carpio*
Longnose sucker	-	*Catostomus catastomus*
White sucker	-	*Catostomus commersoni*
Mountain sucker	-	*Catostomus platyrhynchus*
Blue sucker	-	*Cycleptus elongatus*
Shorthead redhorse	-	*Moxostoma macrolepidotum*
Black bullhead	-	*Ictalurus melas*
Yellow bullhead	-	*Ictalurus natalis*
Channel catfish	-	*Ictalurus punctatus*
Stonecat	-	*Noturus flavus*
Burbot	-	*Lota lota*
Rock bass	-	*Ambloplites rupestris*
Green sunfish	-	*Lepomis cyanellus*
Pumpkinseed	-	*Lepomis gibbosus*
Smallmouth bass	-	*Micropterus dolomieui*
Largemouth bass	-	*Micropterus salmoides*
White crappie	-	*Pomoxis annularis*
Black crappie	-	*Pomoxis nigromaculatus*
Yellow perch	-	*Perca flavescens*
Sauger	-	*Stizostedion canadense*
Walleye	-	*Stizostedion vitreum vitreum*

Sources: Modified from Northern Great Plains Resource Program (1974), Montana Department of Natural Resources and Conservation (1976a), U.S. Geological Survey (1976), U.S. Geological Survey and Montana Department of State Lands (1977), and the Montana Department of State Lands (1977). Common and scientific names of fishes are from Bailey et al. (1970).

the rough and forage fish such as carp (*Cyprinus carpio*), stonecat (*Noturus flavus*), mountain sucker (*Catostomus platyrhynchus*), and flathead chub (*Hybopsis gracilis*).

The Powder River itself supports no significant fisheries because of its great annual fluctuations in flow. However, several tributaries to the Powder River support rough and forage fish as well as game species. Clear Creek downstream of Kendrick Dam contains a fair population of channel catfish and a small number of sauger. Along with these species, good populations of rainbow trout and brown trout occur from the 8-kilometer bridge downstream of Buffalo to the junction of the North and Middle Forks Clear Creek. Trout are also found in the headwaters of the Middle Fork Powder River until its junction with Red Fork. Downstream of Outlaw Canyon, brown trout are the most abundant game fish compared to upstream where brook trout and some rainbow trout may be found. At the mouth of the North Fork Powder River some mountain sucker, white sucker, flathead chub, longnosed dace, and stonecat occur with abundant populations of brown and rainbow trout; trout populations, however, disappear in the downstream portions of the Powder River.

The Tongue River Basin supports several fisheries with the upper portions particularly well stocked with brown trout and mountain whitefish. Although downstream, near Dayton, manmade additions such as roads and farms lower stream productivity, brown trout and mountain whitefish remain the most abundant species. As the Tongue River flows through the farming areas in northern Wyoming, productivity is further reduced, and game fish such as trout and mountain whitefish occur but are far outnumbered by the carp, sucker, and other forage fish. Currently, the State of Wyoming is working on improving the fisheries habitat of this area.

From the Tongue River Irrigation Reservoir in Montana to Birney, the fishing is very good. State record-size black and white crappie have been recently caught in Tongue River Reservoir (Personal communication, L. Peterson, Montana Fish and Game Information Division, Helena, Montana, 1978). However, downstream from Birney, agricultural practices have increased water temperatures and nongame species predominate. Above the T&Y Diversion near Brandenburg, the waters are too warm for trout to survive. Below the T&Y Diversion, the Tongue is characterized by species entering from the Yellowstone River, such as the paddlefish, carp, sauger and walleye. The mouth of the Tongue River is believed to be important as a catfish spawning and nursery area.

MINERAL RESOURCES

Mining deposits found in Montana and Wyoming include such minerals as silver, gold, copper, molybdenum, nickel, gypsum, manganese, uranium, and zinc (Krohn and Weist, 1977). However, in the Tongue and Powder River Basin areas, bentonite and coal are the only minerals actively mined. Some trace metals associated with coal mining in the basins include cadmium, mercury, molybdenum, lead, uranium, and beryllium; most of the coal deposits also have limited amounts of clinker, which is used in building hauling roads and in railroad ballasts (Glass, 1977). Sand and gravel production is present in all the counties but is limited.

5. ENERGY RESOURCE DEVELOPMENT

ACTIVE DEVELOPMENT

Oil and Gas

The total production of crude oil and condensate for Montana and Wyoming in 1972 was 14.6 thousand m^3/day and 62.3 thousand m^3/day, respectively (U.S. Geological Survey and Montana Department of State Lands, 1977). However, only a few oil and gas fields are distributed throughout the Tongue and Powder River Basins.

The area supports production from the Belle Creek field in Powder River County, Montana (Missouri River Basin Commission, 1978b), and from the Ash Creek field about 12.9 km west of the Decker Mine on the Montana-Wyoming line. Approximately 795 million liters of oil has been obtained from the Cody Shale of this latter field. The Salt Creek field in Natrona County, second largest crude oil field in Wyoming, produced 1.6 billion liters of oil in 1975 (Missouri River Basin Commission, 1978b). The only other oil and gas production is in the Crow Ceded Area and is found in the Synder field, approximately 40 km south of Bighorn, Wyoming (U.S. Bureau of Indian Affairs, 1974).

The Yellowstone-Tongue Areawide Planning Organization (1977) has expressed concern over possible long-term effects of chemicals being used in the tertiary recovery of petroleum in the Belle Creek field. It is expected that the chemicals are nontoxic and should stay confined to the geologic formation from which the oil is being extracted. However, no environmental assessment of the project has yet been made, and the Yellowstone-Tongue Areawide Planning Organization (1977) recommends that data be collected on the long-term effects of these chemicals, as well as the potential for leakage to ground water, before any additional large-scale extracting activities from the area are authorized.

Coal

Substantial amounts of fossil fuels must be extracted in the near future in order for the United States to both satisfy increasing energy demands and achieve energy self-sufficiency. Coal, 1,000 kg of which is equivalent to the heating value of 788 liters of oil, is the most likely candidate to be used to offset shortages in domestic gas and liquid fuel production. Already coal is gaining in importance in the generation of western electrical power, and the decline of natural fuel supplies has also promoted research into conversion of coal to gas and liquid fuels through gasification and hydrogenation (U.S.

Bureau of Reclamation, 1972). It is estimated that the national projected need for coal will rise from a 1974 level of 547 billion kg to 1.2 trillion kg in 1980 and 1.9 trillion kg in 1985 (Atwood, 1975).

The vast majority of minable coal in the United States (72 percent of the Nation's coal resources) is found in the Rocky Mountain and Northern Great Plains provinces (Atwood, 1975). Western coal is particularly attractive, since 43 percent of it is located in thick seams, is close enough to the surface to strip mine, and is mostly of low sulfur content (Atwood, 1975). The size of western coal fields is also well suited to establishment of large adjacent gasification and liquefaction plants.

Approximately 75 percent of Montana's strippable coal is found in the Tongue and Powder River Basins (Missouri River Basin Commission, 1978b). The extensive deposits are situated primarily in the Tongue River Member of the Fort Union Formation (Figure 8) and are comprised of alternating layers of sandstone, shale, and coal (U.S. Bureau of Reclamation, 1972). These flat coal-bearing rocks are generally situated close to the surface, and localized erosion has produced frequent areas of exposure along canyon walls. Quality of the coal is variable, ranging from 0.2 to 2.0 percent sulfur content, with most samples falling below 1.0 percent. Heat content ranges from 15,000 to 19,300 joules/g for the lignites in the study area, and from 19,300 to 22,100 joules/g for the subbituminous "C" coal (U.S. Bureau of Reclamation, 1972).

It is estimated that throughout eastern Montana and Wyoming and western North and South Dakota there exist 31 trillion kg of strippable coal reserves, 17 trillion of which are considered economically recoverable (U.S. Bureau of Reclamation, 1972). Average thickness of the coal beds ranges from 2 to 40 m, and maximum overburden ranges from 24 to 91 m.

There are a number of major strip mines presently in operation throughout the study area (Glass, 1976), as well as a number of proposed new mines and expansions (Figure 8). A brief discussion of these mining operations follows.

West Decker Mine--

The West Decker Mine is located in the southeastern corner of Big Horn County, approximately 8 km north of the Montana-Wyoming State line and 32 km northeast of Sheridan, Wyoming. This open-pit coal mine occupies approximately 12.5 km^2 and has been operational since 1972 (U.S. Geological Survey and Montana Department of State Lands, 1977). In 1975, the mine produced 8 billion kg of coal from the Anderson-Dietz coal beds (Table 16), all of which was exported to electrical generating plants in Illinois (Table 17). It is expected that production will soon be increased to 9 billion kg/yr, a level that will be maintained until existing resources are depleted (U.S. Geological Survey and Montana Department of State Lands, 1977).

Decker Coal Company has submitted proposals for expansion to the north of the existing mine and development of an additional mine on the east side of the Tongue River Reservoir. The new East Decker Mine would cover 15.0 km^2 and would provide coal to the Lower Colorado River Authority in Austin, Texas, and Commonwealth Edison of Chicago, Illinois (U.S. Geological Survey and Montana Department of State Lands, 1977). This proposed mine would intercept

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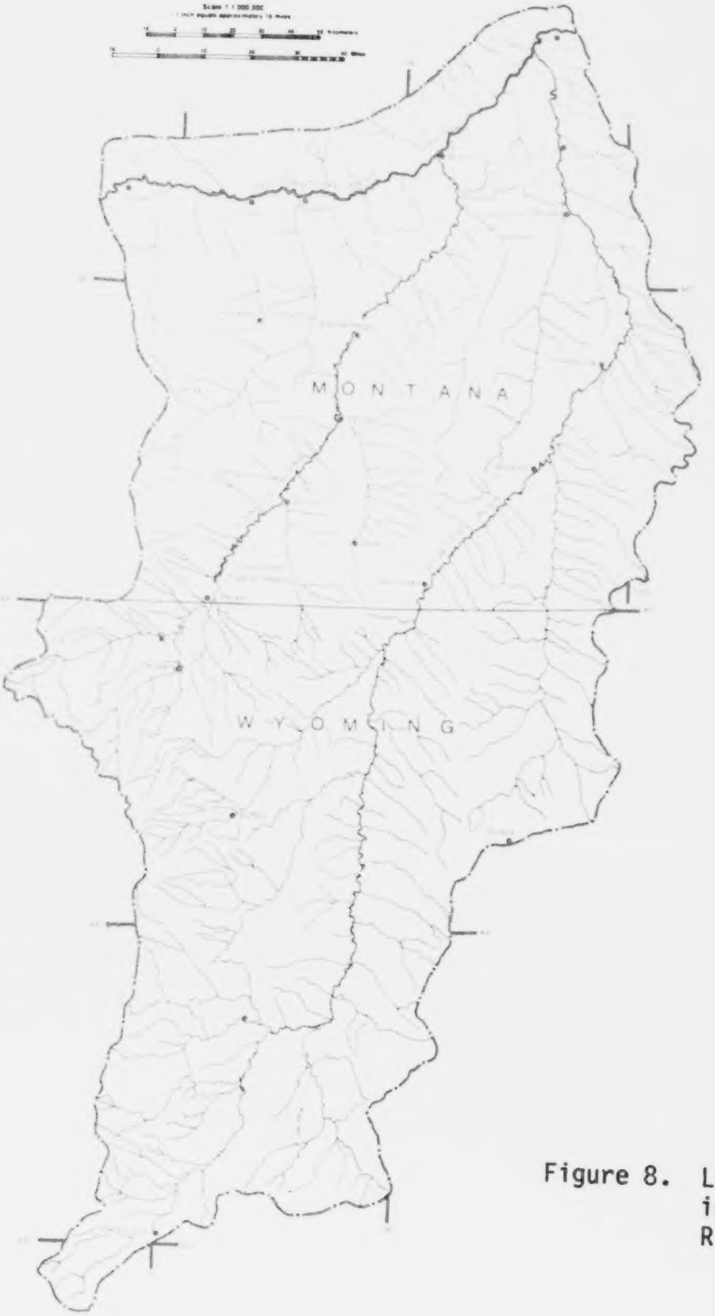
MONTANA
WYOMING

Figure 8. Location of coal mines in the Tongue and Powder River Basins.

TABLE 16. LIST OF STRIPPABLE SUBBITUMIOUS AND LIGNITE COAL FIELDS IN THE POWDER, TONGUE, ROSEBUD, SARPY, AND ARMELLS CREEKS WATERSHEDS IN MONTANA

Name of Field	Coal Bed	Est. Reserves (millions of kg)	Km^2	Average (million kg/km^2)	Ash	Sulfur	Btu
Decker	Anderson-Dietz 1&2	2,031,671	103.29	19,670	4.0	0.40	9,652
Deer Creek	Anderson-Dietz 1&2	449,554	57.52	7,816	4.0	0.50	9,282
Roland	Roland	197,762	48.87	4,047	9.2	0.74	8,164
Squirrel	Roland	121,003	25.12	4,817	5.5	0.29	7,723
Kirby	Anderson	196,384	22.89	8,579	4.2	0.32	8,328
	Wall	429,637	24.09	17,835			
	Dietz	756,755	70.89	10,675	5.8	0.59	8,509
	Canyon	143,787	16.45	8,741	5.8	0.24	8,789
Canyon	Wall	1,709,015	96.56	17,699	4.6	0.30	9,088
	Brewster-Arnold	59,735	8.37	7,137	7.5	0.40	8,444
Birney	Brewster-Arnold	163,759	28.20	5,807	5.1	0.41	9,055
Poker Jim Lookout	Anderson-Dietz	791,494	79.36	9,973	5.2	0.37	7,925
Hanging Woman Creek	Anderson	1,436,044	123.62	11,617	4.9	0.29	8,496
	Dietz	1,016,710	176.67	5,755	5.5	0.33	8,078
West Moorhead	Anderson	801,552	79.56	10,075	5.3	0.36	8,296
	Dietz	360,523	82.62	4,364	4.1	0.41	7,990
	Canyon	626,002	91.25	6,860	5.6	0.45	8,055
Poker Jim O'Dell	Knobloch	338,574	31.93	10,604	5.1	0.22	8,846
	Knobloch	512,255	29.09	17,609			
Otter Creek	Knobloch	1,882,524	104.37	18,037	4.7	3.60	8,468
Ashland	Knobloch	2,445,453	110.08	22,215	4.8	0.15	8,421
	Sawyer A&C	324,243	82.00	3,954	4.9	0.49	7,883
Colstrip	Rosebud	1,305,409	135.08	9,664	9.5	0.12	8,836
Pumpkin Creek	Sawyer	2,200,836	184.93	11,901	7.5	0.34	7,438
Foster Creek	Knobloch	642,274	112.51	5,709	7.8	0.76	7,573
	Terret	418,009	111.14	3,761	5.8	0.21	7,770
	Flowers-Goodale	234,822	58.45	4,017	7.8	0.51	7,553
Broadus	Broadus	671,017	74.58	8,997	7.2	0.27	7,437

(Continued)

TABLE 16. (Continued)

Name of Field	Coal Bed	Est. Reserves (millions of kg)	Km^2	Average (million kg/km^2)	Ash	Sulfur	Btu
East Moorhead	T	476,365	62.97	7,565	6.2	0.57	7,120
Diamond Butte	Canyon	379,144	86.45	4,386	4.8	0.43	7,330
Goodspeed Butte	Cook	570,458	54.42	10,482	10.6	1.63	6,771
Fire Gulch	Pawnee & Cook	305,378	34.34	8,893	3.8	0.33	7,739
Sweeney-Snyder	Terret	296,981	44.20	6,719	9.1	0.11	8,175
Yager Butte	Elk & Dunning	1,066,505	108.96	9,788	4.8	0.33	7,646
	Cook	283,002	58.71	4,820	6.7	0.63	7,254
Threemile Buttes	Canyon & Ferry	204,438	55.99	3,651	5.5	0.94	6,867
Sonnette	Pawnee	290,467	33.28	8,728	9.8	0.88	6,964
	Cook	329,223	42.37	7,770	8.1	1.23	6,891
Home Creek Butte	Canyon & Ferry	197,009	19.63	10,036			
Little Pumpkin Creek	Sawyer A&C, D, X, & E	195,758	34.54	5,668			
Sand Creek	Knobloch	242,477	24.09	10,065	6.6	0.30	7,340
Beaver-Liscom	Flowers-Goodale & Terret	123,234	35.82	3,440	8.1	0.96	8,102
	Knobloch	445,899	69.10	6,453	7.7	0.50	8,027
Greenleaf-Miller Creek	Rosebud, Knobloch, and Sawyer	411,515	60.37	6,816	7.5	0.71	8,422
Pine Hills	Dominy	175,840	24.37	7,215	7.2	0.53	7,293
Knowlton	Dominy (M&L)	677,992	79.37	8,542	7.1	0.41	6,710
	Dominy (U)	109,121	18.00	6,062	5.6	0.38	6,645
Sarpy Creek	Rosebud-McKay	1,360,500	171.48	7,934	6.5	0.50	8,600
Cheyenne Meadows	Knobloch	1,088,400	54.88	19,832	4.1	0.40	8,400
Little Wolf	Rosebud-McKay	284,798	29.99	9,496			
Jeans Fork		81,630	15.38	5,308			
Wolf Mountains		1,743,254	125.46	13,895			

Source: Modified from Montana Bureau of Mines and Geology (1977).

TABLE 17. SUMMARY OF EXISTING MINES WITHIN 160KM OF THE CECKER MINE, TONGUE RIVER BASIN, MONTANA

Name of Mine	Operator	Coal Ownership	Start of Production (year)	1976 Annual Production (million kg)	Utilization of Coal	Market Areas
West Decker	Decker Coal Company	Federal and State	1972	9,251	Electrical power generation	Illinois
Big Horn	Big Horn Coal Company	Private	1944	1,633	Electric power generation, industrial and domestic heating	Wyoming
Colstrip (Rosebud)	Western Energy Company	Federal and private	1968	8,435	Electric power generation, industrial heating	Minnesota, Illinois, North Dakota, Montana
Big Sky	Peabody Coal Company	Federal and private	1969	2,177	Electric power generation	Minnesota
Sarpy Creek (Absolaka)	Westmoreland Resources	Indian	1974	3,719	Electric power generation	Iowa, Wisconsin, Minnesota
Ash Creek	Ash Creek Mining Company	Private	1978*	454**	Electric power generation	Oklahoma

*No Coal Production to date.
**Estimated production rate after 1978.

Source: Modified from U.S. Geological Survey and Montana Department of State Lands (1977).

three major river drainages: Deer Creek, Coal Creek, and Middle Creek. In order to prevent runoff from these watersheds from entering the mining area, a number of impoundments and diversion channels would be built. The largest of these structures would divert all flow out of the present Deer Creek channel into a sediment settling pond 3,000 m away to the north of the mine area (U.S. Geological Survey and Montana Department of State Lands, 1977). Water from this pond would then be discharged into an ancient channel of the Tongue River where it would flow northwestward into a bay of the Tongue River Reservoir. Smaller structures would be built to intercept and divert any runoff from Middle and Coal Creek valleys out of the mining area.

The North Expansion area would cover 9.4 km^2 and would provide coal to be shipped to Detroit, Michigan, for use in electrical power generation (U.S. Geological Survey and Montana Department of State Lands, 1977). This expansion would cross both Spring Creek and Pearson Creek valleys; diversion channels for these drainages would be built. Decker Coal Company estimates 189 m^3/day of ground water would also enter the mining pits from exposed aquifers (U.S. Geological Survey and Montana Department of State Lands, 1977). This ground water would be pumped into two mine water treatment ponds, where water would be treated before being released into natural drainages. Water for dust control would be obtained from these ponds.

Existing treatment ponds are not adequately preventing chemical effluents from the mine from entering the Tongue River Reservoir. Discharges associated with the Decker Mine are characteristically high in sodium bicarbonate, with concentrations of dissolved constitutents ranging from about 675 to 3,400 mg/l with common values between 1,500 and 2,500 mg/l (U.S. Geological Survey and Montana Department of State Lands, 1977). As much as 70 to 80 percent of this effluent enters the reservoir from the highly permeable clinker that lines the reservoir shores (U.S. Geological Survey and Montana Department of State Lands, 1977). This problem may be solved with the opening of a box cut along the west and north margins of the proposed mine area, which would create a new sink, or low point, in the ground-water flow system. Installation of holding tanks or settling ponds where discharge waters could be lost to evaporation or properly treated would also be valuable if these tanks or ponds prevented high salinity waters from entering the river.

The existing West Decker facilities consume an estimated 442,088 m^3/yr of ground water (Personal communication, Bob Jerere, Decker Coal Company, Decker, Montana, 1978). The East Decker Mine will consume 82,892 m^3/yr of water; 88 percent of this total will be for dust control, washing equipment, and fire control with the remaining 12 percent being used for human consumption and sanitation purposes (U.S. Geological Survey and Montana Department of State Lands, 1977). Of the 82,892 m^3/yr, 73,000 m^3 of water will be obtained from mine effluent and the remainder from existing wells. The North Decker Expansion, it is estimated, will consume 41,464 m^3/yr of water for dust control; all other water needs will be met with the existing West Decker Mine facilities (U.S. Geological Survey and Montana Department of State Lands, 1977).

Rosebud-Tongue River Mine--

The Rosebud-Tongue River Mine was a small surface coal mine covering parts of two 0.16 km^2 tracts within the presently proposed North Expansion Decker Mine area (U.S. Geological Survey and Montana Department of State Lands, 1977). The mine, owned by Peter Kiewit Sons, Company, in Sheridan, Wyoming, operated intermittently from 1954 to 1970, and provided coal that was used by residents in the vicinity for heating and cooling purposes. Total production from the now inactive mine was about 31.7 million kg coal (U.S. Geological Survey and Montana Department of State Lands, 1977); both tracts of the small mine would be included in the North Decker Expansion facility.

Colstrip (Rosebud) Mine--

The Colstrip (Rosebud) Mine is located at Colstrip, Montana, between Rosebud Creek and the Tongue River. Colstrip opened in 1924 and was operated by the Northwestern Improvement Company until 1958. The relatively wide southeastern end of the mine has been developed by Western Energy Company since 1968. By 1974 about 8.09 km^2 of land had been disturbed, and as much as 40.5 km^2 may ultimately be affected.

In 1976, approximately 8,435 million kg/yr of subbituminous coal was produced. This coal is used for electrical power generation and industrial heating throughout Montana, North Dakota, and Minnesota (Van Voast et al., 1975).

Colstrip now imports 52,480 m^3/day of water from the Yellowstone River 48 km away, but additional water totalling 13.7 million m^3/yr will be required for future mine activities (dust control, handling, crushing, and service water), reclamation, and expansion of municipal facilities (University of Oklahoma and Radian Corporation, 1977b; Van Voast, 1974). Of the additional 6.07 million m^3/yr used for municipal purposes, 0.5 million m^3 will be drawn from ground-water sources. Most of the imported water will be utilized by two coal-fired steam generation plants recently constructed at Colstrip (Van Voast and McDermott, 1977). Discharges from the facilities at Colstrip will be put into holding tanks and settling ponds where the water will be lost to evaporation or be reused (University of Oklahoma and Radian Corporation, 1977b).

Ash Creek Mine--

Ash Creek Coal Mine is located near Ash Creek in Sheridan County, Wyoming, near the Montana-Wyoming border. The Ash Creek Coal Company owns and operates the mine but is currently not producing. Estimated production after 1978 will be 453.5 million kg/yr for 28 years (U.S. Geological Survey and Montana Department of State Lands, 1977). The coal will then be trucked 13 to 16 km south and loaded on rail to be shipped to Tulsa, Oklahoma.

By 1979 the total area disturbed will increase from 0.16 to 0.20 km^2 and by 1983 should reach a total of 0.40 to 0.61 km^2 (Personal communication, S. Rogers, Ash Creek Coal Company, Sheridan, Wyoming, 1978). The Ash Creek Coal Company will use three wells for pumping ground-water supplies for mining needs. Discharges from the facilities will be released into several settling ponds.

Welch Mine--

The Welch Mine opened in 1949 and closed in April of 1976. It is located in the Tongue River valley west of Bighorn Mine in Sheridan County, Wyoming. The mine is owned and operated by the Welch Coal Company, a subsidiary of Montana-Dakota Utilities.

While in operation, the mine was producing 8.8 x 10^4 kg/day at an annual production of 27 million kg/yr (Krohn and Weist, 1977). The coal was transported 18 km via a truck line to a small electrical generating station at Acme that has since closed down (August 1976). The Welch Mine was a small operation that disturbed only 0.06 km^2 during the years of production. The demand for water at the mine was such that annual snowfall or runoff from precipitation met the limited needs.

Sarpy Creek (Absaloka) Mine--

The Sarpy Creek Mine, owned by Westmoreland Resources, has been extracting from the Rosebud-McKay seam of coal near the confluence of Sarpy and the East Fork Sarpy Creek since 1974 (U.S. Bureau of Indian Affairs, 1974). The mine is located just north of the Crow Indian Reservation, approximately 105 km east of Billings, Montana. It removes approximately 3.7 billion kg of coal annually (U.S. Bureau of Indian Affairs, 1974), which is transported to the Midwest for use in power generation (Table 17). The mine is expected to ultimately produce 69.8 billion kg of coal over the next 20 years and to disturb a total of 5.2 km^2 of land, 0.8 km^2 of which will be as the result of secondary construction and road development associated with the mining activities.

The existing Absaloka Mine consumes an annual average of 103,614 m^3 of ground water; the bulk of this depletion is for dust control purposes (U.S. Bureau of Indian Affairs, 1974). Any surface runoff passing through the mined property is detained behind a combined railroad embankment-sediment detention dam, which stores 95 thousand m^3 water. This detained water, which tends to be high in alkalinity and suspended colloids, is checked for adherence to water quality standards before being released 3.7 km downstream to a tributary to Sarpy Creek (U.S. Bureau of Indian Affairs, 1974).

Westmoreland has applied for expansion of the existing Absaloka Mine onto 0.93 km^2 of State land and coal (U.S. Geological Survey, 1976). The expansion, which is considered necessary for Westmoreland to satisfy existing contracts for coal, would add three water control facilities and would consume a total of 341 to 946 m^3 of ground water per day (U.S. Geological Survey, 1976). The expansion would affect the upstream portions of several small tributaries that flow into Sarpy, the East Fork Sarpy, and the Middle Fork Sarpy Creeks, as well as destroy the ground-water reservoir above the coal beds in the area mined. It is estimated that 146 million m^3/yr of water from Sarpy Creek would be irretrievably lost as a result of the expansion (U.S. Geological Survey, 1976).

Big Sky Mine--

The Big Sky Mine, part of the Rosebud coal bed (Table 16), is located in the southern portion of Rosebud County about 8 km south of Colstrip, Montana. This open-pit coal mine has been operational since 1969 and by November 1973 had produced 5.6 billion kg of subbituminous, low sulfur coal to be sent to Minnesota Power and Light (Table 18) (U.S. Geological Survey, 1974). The mine, operated by Peabody Coal Company, disturbs about 0.40 km^2/yr of land for mining activities and will eventually affect 4.04 km^2. By the end of 1973, approximately 40 percent of the disrupted land had been graded and replanted.

An estimated 45,420 m^3/yr of ground water are depleted during mining operations, primarily for dust control purposes (U.S. Geological Survey, 1974). This water is temporarily detained in settling ponds created by cuts in the land and ultimately is discharged back into East Fork Armells Creek (Van Voast, 1974).

TABLE 18. YEARLY PRODUCTION OF COAL, BIG SKY MINE, MONTANA

Year	Production (kg)
1969	148 million
1970	1.304 billion
1971	1.356 billion
1972	1.452 billion
1973 (to November 1)	1.500 billion
1976	2.177 billion

Sources: Modified from U.S. Geological Survey (1974), and U.S. Geological Survey and Montana Department of State Lands (1977).

Bighorn Mine--

The Bighorn Mine is located in Sheridan County, Wyoming, approximately 16 km north of Sheridan in the foothills of the Big Horn Mountains. It is owned and operated by the Bighorn Coal Company, a subsidiary of Peter Kiewit Sons, Company. The company holds two leases: a Federal lease of 0.32 km^2 and a State lease of 2.59 km^2.

The mine was opened in 1944 and has grown to a 1975 production rate of 713.8 million kg/yr with production levels expected to reach 1,360 million kg/yr by 1980 (Krohn and Weist, 1977).

Coal mined at Bighorn is distributed to several power and public service companies throughout the country, including the Illinois Power Company in Chicago, Kansas City Power and Light Company in Missouri, and the Northern States Power Company and the Northwestern Public Service Company, both in South Dakota (Krohn and Weist, 1977).

The mine is traversed by two perennial streams, Goose Creek and Tongue River, which have been diverted through final cuts of old stripping operations and spoil areas (Dettman et al., 1976). Diversion of the streams through old strip mine pits creates numerous small ponds; the confluence point of Tongue and Goose Creeks downstream is located near the point of pumped mine effluent, which contributes a discharge of approximately 0.14 m^3/sec to the downstream Tongue River flow. Discharges from the mine are high in salt levels, particularly sodium and sulfates; however, water quality impact from operation of the Bighorn Mine is small compared to other land use effects, such as agricultural runoff, in the watershed.

Rawhide Mine--

The Rawhide Mine, owned and operated by the Carter Mining Company, is located north of Gillette, Wyoming, at the edge of the Powder River Basin. The mine opened in August 1977 and produces subbituminous to lignitic coal below an overburden varying from 7 to 73 m in depth (Glass, 1976). Peak production is estimated to reach 1.1×10^{10} kg by 1980, and mining operations will consume 757 m^3/day of water. Necessary water for mining is obtained from a number of ground-water sources. Effluents released from the mine are discharged into sedimentation ponds and ultimately used for dust control and road maintenance.

Reclamation--

Successful rehabilitation of the existing and proposed mining areas rests not only on the physical potential of the land but on an effective administrative policy. Such efforts as the Packer system of classification rate the rehabilitation potential based upon the elements of soil (productivity and stability), vegetation (suitability and availability), precipitation (amount and seasonal distribution), and potential moisture-holding capacity (Missouri River Basin Commission, 1978a). These elements are combined to arrive at a numerical rating from +9 to -9 (very good to very poor) with zero equaling fair. The Tongue and Powder Basins lie in the fair to good range (Table 19); however, with increasing energy development, which will affect moisture-holding capacity and soil stability in these arid basins, the rehabilitation potential of the Tongue and Powder River drainages is expected to get increasingly worse.

TABLE 19. REHABILITATION POTENTIAL RATINGS FOR COAL PRODUCING AREAS IN THE TONGUE AND POWDER RIVER BASINS USING THE PACKER SYSTEM OF CLASSIFICATION

Location	Size of Rehabilitation Area (Km^2)	Rating
Tongue and Powder River Basins, Montana	2,161	+1.09
Northeast Wyoming	1,708	-0.47
Overall	3,869	+0.62

Source: Modified from Missouri River Basin Commission (1978a).

Reclamation of stripped areas is difficult in regions of low precipitation where sufficiently large quantities of water are not available to allow reestablishment of plant cover. Most of the Tongue-Powder study area receives between 30 and 40 cm of rainfall annually. However, 75 percent of this rainfall occurs between April and September when prevailing summer westerly winds deplete the available soil moisture. This semiarid environment places limitations on the availability of water for rehabilitation.

Montana's Water Resources Act of 1967 and the Wyoming Environmental Quality Act of 1973 created powers to control and oversee most of the problems associated with the development and reclamation of mined or industrial land (Montana Department of Natural Resources and Conservation, 1976c). Terms of the Wyoming Environmental Quality Act require rehabilitation of surface-mined land to equal or better conditions. Revegetation of disturbed lands, topsoil stockpiling and reuse, and the prevention of erosion and water pollution are also included under the Wyoming Environmental Quality Act (Missouri River Basin Commission, 1978a).

Powerplants

As the expansion of coal mining continues in the study area, the development of coal-burning powerplants is expected to increase. Existing powerplants in this region are currently meeting present demands. However, at present (1977) there is virtually no capacity in the existing plants that is not committed to some use, either within or outside the study area. Any substantial new load that may develop will have to be met by either additional capacity in the area or importation of energy (Missouri River Basin Commission, 1978a).

There are no major hydroelectric power facilities in the area and the opportunity for such is very limited. However, there are two coal-fired powerplants at Colstrip and one gas turbine at Miles City (Table 20). Although there are presently not many powerplants in the area, a good number have been proposed for the Tongue and Powder River study area (Table 21). By the year 2000 water consumption from power facilities is projected at 102.3 million m^3/yr, which is equivalent to about 1.1 percent of the average annual flow and about 12 percent of the extreme low flow recorded in the Tongue River at Miles City (University of Oklahoma and Radian Corporation, 1977a).

TABLE 20. EXISTING POWERPLANTS IN THE TONGUE-POWDER RIVER STUDY AREA

Location	Operating Co.	MW	Water Consumption (m^3/day)	Diversion Source
Colstrip	Montana Power Company	680	15,000 - 18,000	Yellowstone
Miles City	Montana Dakota Utilities	23	Air cooled	--

Source: Personal communication, Bob Anderson, Montana Department of Natural Resources, Helena, Montana, 1978.

Presently at Colstrip there are operational two 350 MW units, which each divert 19 thousand m^3/day of water for use (Montana Department of Natural Resources and Conservation, 1977). Most of this diversion, which includes municipal water from the town of Colstrip, is lost to evaporation from the cooling towers. Colstrip Units 3 and 4, if made operational, will have a generation capacity of 700 MW each and will each divert 13 million m^3/yr of

TABLE 21. PROPOSED POWERPLANTS IN THE TONGUE-POWDER RIVER STUDY AREA

Plant Location	Coal Deposit	Plant Size (MW)	No. of Pumping Plants	Annual Energy at Load Center (million kWh)	Annual Water Delivery ($m^3 \times 10^6$)
Colstrip	Colstrip	5,000	4	78.0	67.8
NW of Brandenburg	Sweeney Creek	1,000	3	10.0	13.5
SE of Ashland	Otter Creek	5,000	2	19.0	67.8
Birney	Birney	1,000			13.5
Birney-PJ	Poker Jim Lookout	1,000			13.5
S of Birney	Hanging Woman Creek	10,000	2	53.0	135.6
Kirby Alt. 1	Kirby	1,000	5	21.0	13.5
Kirby Alt. 2	Kirby	1,000	3	10.0	13.5
Decker	Decker	5,000			67.8
Volborg	Foster Creek	5,000	5	76.0	67.8
Camps Pass	Pumpkin Creek	10,000	7	228.0	135.6
Sonnette	Sonnette	1,000	5	20.0	13.5
Broadus	Broadus	3,000			40.7
Moorhead	Moorhead	5,000			67.8
Sheridan		2,000			
Spotted Horse	Spotted Horse	3,000			40.7
Lake De Smet	Lake De Smet	10,000			135.6

Source: Modified from North Central Power Study (1971).

water, most of which will also be lost to the atmosphere during the cooling process (Montana Department of Natural Resources and Conservation, 1977). If anticipated expansion of development at Colstrip continues, this total generating capacity of 2,100 MW may be reached by 1979. The Colstrip Mine would then have the capacity to produce up to 7.2 billion kg of coal per year.

Future powerplants may implement several different means of generating electricity. They may directly burn coal using a magnetohydrodynamic process or may implement the resources derived from the gasification-liquefaction of coal (U.S. Department of Interior, 1975). The power generated by either Colstrip or the other proposed plants may be distributed to centers of population in Oregon, California, and Illinois.

FUTURE DEVELOPMENT

Coal Gasification and Liquefaction Plants

There are currently no gasification plants in the area; however, future developments are in the planning stages and should be in operation in the 1990's (University of Oklahoma and Radian Corporation, 1977b).

The Missouri River Basin Commission (1978a) indicates that the cost of producing gas and liquid fuels via gasification and liquefaction will exceed the cost of energy from other sources through the years 1990 to 2000. After 1990, Federal funds coupled with exhausted or dwindling domestic reserves of natural gas and oil may result in expansion of coal gasification-liquefaction activity. A total of 14 coal gasification plants are proposed for the Yellowstone area, four of them in the Tongue and Powder River Basins (Table 22). Water requirements will depend on the type of system implemented.

The Lurgi Pressure Gasification Process, the Synthane high Btu, IGT (Institute of Gas Technology) HYGAS gasification process, or the Synthoil coal liquefaction and Fisher-Tropsch synthesis are the most likely major processes to be used (University of Oklahoma and Radian Corporation, 1977b). The Lurgi Pressure Gasification, HYGAS, and the Synthane gasification processes produce high Btu synthetic gases and differ from the Synthoil liquefaction process, which produces fuel oils or gasoline (U.S. Environmental Protection Agency, 1977a). Underground in situ gasification processes are also being examined and tested for feasibility at the Colstrip area.

Water is the primary resource required for synthetic gas production. It is used for both the processing and cooling associated with each of the different methods. In processing, the water is used to generate steam and supply hydrogen for reactions (Table 23) in the gasification/liquefaction processes (Northern Great Plains Resource Program, 1974). Water is also utilized for ash quenching, sluicing, and dust control. The amount of water consumed by each plant will depend upon the plant characteristics and the water conservation practices that are implemented. Whether ground water or surface water is used for future development will depend on its quality and availability. However, most of the proposed liquefaction-gasification plants

TABLE 22. FUTURE COAL LIQUEFACTION-GASIFICATION PLANTS IN THE TONGUE AND POWDER RIVER BASINS

Company	Location	Capacity MMCMD	Remarks
Gasification			
Texaco, Inc.	Story, WY	0.8	Will be supplied with coal from Texaco, Lake De Smet Coal Mine.
Northern-Natural Gas Co.	Northern Cheyenne Indian Reservation, Big Horn or Rosebud Counties	7.5 - 15.0	Initial operation date 1981 (2 units); in 1984, 2 more units added. Each unit will produce a minimum of 7.5 m^3/day. The Peabody Coal Company will supply an estimated rate of 24 million kg/day for each of the 4 units.
Colorado Interstate Gas Co.	SE Montana	7.5 - 15.0	Will implement 2 units by early 1990's.
Liquefaction			
Exxon Carter Oil	N. Wyoming	3.6	Only 1 unit planned.

MMCMD = Million cubic meters crude oil or gas per day.

Source: Modified from Corsentino (1976) and Harza Engineering Company (1976).

plan to utilize ground water, which will deplete the shallower aquifers. The quality of these sources is poor and depletion will demand the use of new aquifers at greater depths.

Whatever process is implemented, the water consumed per unit of energy produced through gasification is less than is consumed for continual power generation. Through gasification, 7.08×10^3 Btu is produced for each cubic meter of water consumed, as compared with conventional steam electrical generation of approximately 1.4×10^3 Btu per cubic meter of water consumed.

TABLE 23. ANTICIPATED WATER REQUIREMENTS FOR ENERGY FACILITIES IN THE COLSTRIP, MONTANA, AREA IN THE YEAR 2000

Facility	Size	Anticipated Water Requirement ($m^3 \times 10^6$)
Power generation	3,000 MW (electricity)	46.1-51.8
Coal gasification (Lurgi)	7.08 million m^3/day	5.9-8.7
Coal gasification (Synthane)	7.08 million m^3/day	10.3-12.4
Coal gasification (Synthoil)	15.9 million liters	13.4-23.9
Coal mining	51,517 million kg/yr	1.5

Source: Modified from University of Oklahoma and Radian Corporation (1977b).

Coal Slurry Line

There are currently no coal slurry lines in the Tongue-Powder River Basin study area. In fact, in the State of Montana there presently exists a ban on interstate slurry pipeline operations, which the Missouri River Basin Commission (1978b) has recommended be reconsidered in a recent study of the region. It is expected that with the expansion of in situ gasification, liquefaction, and electrical generation plants, slurry lines may prove to be the most efficient and desirable means of supplying coal to these regional facilities and a number of pipelines have been proposed for the basins (Table 24).

There are a number of potential water quality impacts that may result from development of slurry pipelines, however. Pipeline breaks or deliberate dumps, which would result if the slurry flow becomes plugged and stopped for more than a few hours, could discharge thousands of tons of slurry onto the ground (University of Oklahoma and Radian Corporation, 1977b). If this disposal site is not impermeably lined, contaminated water from the discharged slurry could percolate into the soil, and wind dispersal of the dried coal and evaporites is likely. Large quantities of water would then be required to flush the pipeline before slurry flow could commence; disposal of this flushing water, now contaminated with suspensoids of coal, poses an additional environmental hazard.

TABLE 24. COAL SLURRY PIPELINES PROPOSED IN THE TONGUE-POWDER RIVER BASIN STUDY AREA

Operating Company	Proposed Route		Initial Operating Date	Capacity (kg x 10^{10}/yr)	Length (km)	Water Source and Requirements	Remarks
	Origin	Destination					
Brown & Root, Inc., Houston, TX, and Texas Eastern Transmissions Corp., Houston, TX	Southeastern Montana (Big Horn or Rosebud Counties)	Houston, Texas	Unknown	1.9 - 2.6	2,032	?	Proposed line will transverse southeastern Montana, Wyoming, Nebraska, Oklahoma, and Texas. Planning is in progress.
Energy Transportation Systems, Inc., Casper, WY	South of Gillette, Campbell County	White Bluff, Arkansas	1980	2.2	1,671	18.5 million m^3/yr from underground wells in the Madison Formation	Delayed in obtaining rights-of-way across railroad line. The project is suspended until the required legislation authorizes the right of eminent domain. Proposed route will cross Wyoming, Nebraska, Kansas, Oklahoma, and Arkansas.
Gulf Interstate Engineering Co., Houston, TX, and Northwest Pipeline Co., Salt Lake City, UT	Near Gillette, Campbell County	Boardman, Oregon	1980	0.9	1,774		Proposed route will cross Wyoming, Idaho, and Oregon.

Source: Modified from Corsentino (1976).

Uranium

Production of uranium from the study basins continuously declined throughout the early and middle 1960's, dwindling to virtual extinction in 1968. There is, however, currently one functioning uranium mine bordering on the Powder and Belle Fourche River Basins. As of 1976, Exxon (Humble Oil Company) near Douglas, Wyoming, has been operating a nominal facility with processing capacity of 2.7 million kg of ore daily (Missouri River Basin Commission, 1978a). Future developments in this region will depend on the interest in prospecting and cost of developing ore-producing plants.

Water pollution from the uranium industry is primarily related to milling activities rather than to conventional mining. In addition to radioactive components that leach or erode from the tailings piles, milling wastes are frequently high in total dissolved solids and either strongly acidic or alkaline (Upper Colorado Region State-Federal Inter-Agency Group, 1971). Other potential sources of exposure from tailings piles include inhalation of wind-blown particulates or gases diffusing from the piles, and external whole body gamma exposure from the piles (Douglas and Hans, 1975).

Extensive exploration by the uranium industry, particularly in southeastern Montana, indicates a potential exists there for solution mining (i.e., in situ leach mining) of uranium in the Fox Hills Formation (Yellowstone-Tongue Areawide Planning Organization, 1977). This process, which is still in the testing stages, takes ore material that has not been transported from its geologic setting and preferentially leaches (dissolves) the ore from its surrounding rock with specific leach solutions (Larson, 1978). This in situ method for recovery of ore minerals is desirable since the relative cost is small compared with traditional underground or open-pit mining. The method does, however, pose the potential environmental hazard of cross contamination between ground-water aquifers. Those leach solutions injected during mineral recovery normally are confined to the geologic zone containing uranium ore. If, however, geologic discontinuities, unplugged drill holes, or corroded well casings are present, a portion of the injected fluids may escape and contaminate surrounding aquifers used for domestic purposes. The Yellowstone-Tongue Areawide Planning Organization (1977) has made a number of recommendations to assure that all precautions are taken against aquifer contamination if the process is implemented. These include: plugging of all exploratory holes to prevent movement of mining fluid; reclamation of the mining zone via flushing or neutralization; monitoring during the mining process, including development of emergency procedures in case escape of injection solutions to overlying or underlying aquifers does occur; and development of a permit program for operators. Such a permit would specify pilot testing, a mandatory bond to cover cost of reclamation and plugging of any drilled well, and examination of the area around each well site for geologic porosity, direction and rate of ground-water migration, and relationship of affected aquifers to nearby water supply wells and surface flows.

TRANSPORTATION OF ENERGY RESOURCES

Transportation of energy resources from the Tongue and Powder River Basins constitutes a significant part of the total environmental impact associated with energy development. Montana and Wyoming are major exporters of coal, gas, oil, and uranium, the transportation of which pose a unique problem. The shipments of coal, gas, or oil are quite different from those originating in the Appalachian and Illinois mines; the distances covered from those fields on the average is less than 186 km, with an occasional line of 310 km. If development occurs as planned in the Montana-Wyoming area, routes as long as 930 km may be common (Campbell and Katell, 1975).

Coal is planned for export to midwestern and other markets via unit trains or coal slurry lines. Coal conversion plants will export gas and oil via pipelines, while powerplants distribute electricity over transmission lines (Figures 9 through 11).

The unit trains transporting the majority of coal mined in the area to terminals in Austin, Texas, Omaha, Nebraska, Chicago, Illinois, and by boat from Superior, Wisconsin, to the Detroit area may account for one-third to one-half of the delivered coal price (Campbell and Katell, 1975). The Pigs Eye Terminal, to be constructed on the Mississippi River at St. Paul, Minnesota, will provide a major rail-waterway transfer and loading facility for distribution to midwestern power utilities (U.S. Bureau of Indian Affairs, 1974).

Local hazards in transportation activities are exemplified by the problems occurring at the East Decker and North Expansion Mines, where some 9.07 million kg of coal is transported on unit trains of 100 cars. These trains obstruct traffic, presenting an increasing hazard of spillage and chance of collision. Each of the mines will require, by the year 2000, the addition of 17 to 18 unit trains per week to the existing 19 to 20 unit trains per week (U.S. Geological Survey and Montana Department of State Lands, 1977). Statistics associated with problems of delivery of coal for 1956-66 show that mine transportation accidents accounted for 19 percent of the fatalities in bituminous coal mines and are second only to roof deficiencies as a cause of death (Curth, 1971).

Coal transport via slurry pipeline can offer lower costs than rail or waterway movement under the proper conditions. However, for all slurry pipelines under consideration, water is needed at the rate of 1 liter water/1 kg coal (Missouri River Basin Commission, 1978a). The prospect of extensive coal slurry development in the arid Tongue and Powder River Basins is not likely because of the lack of both physical and legal availability of surface water supplies. Ground-water resources may be adequate for slurry line development. However, the quantity reliably available for use is at present uncertain, and potential depletion of existing ground-water aquifers is a factor limiting such development.

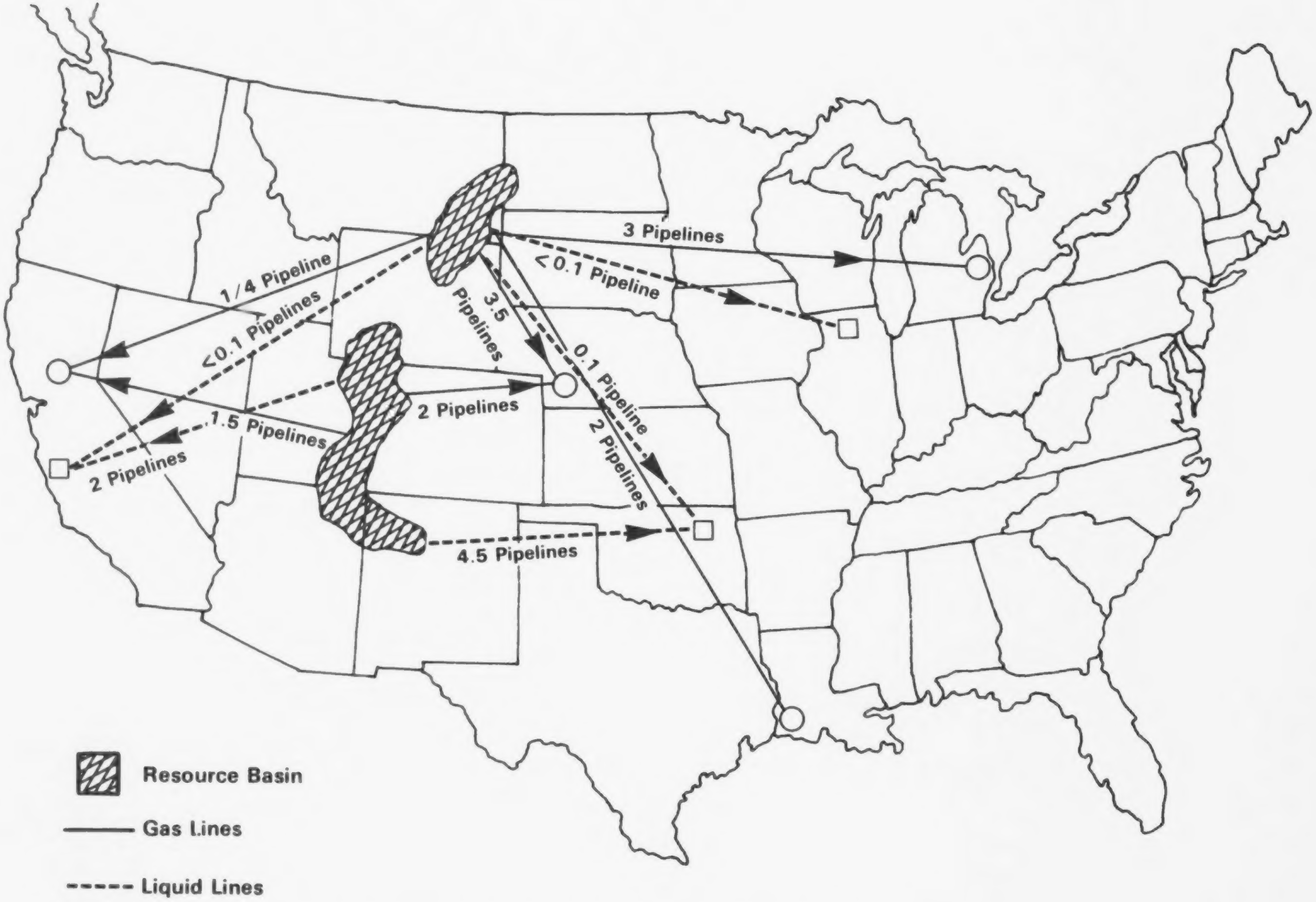
3 Pipelines
< 0.1 Pipeline
1/4 Pipeline
<0.1 Pipelines
3.5 Pipelines
0.1 Pipeline
2 Pipelines
2 Pipelines
1.5 Pipelines
2 Pipelines
4.5 Pipelines
Resource Basin
Gas Lines
Liquid Lines

Figure 9. High Btu gas liquid (crude oil, shale oil, coal syncrude) pipelines proposed by the year 2000 for the Western United States (capacity of each pipeline is 28 million m^3/day). Source: Modified from University of Oklahoma and Radian Corporation (1977b).

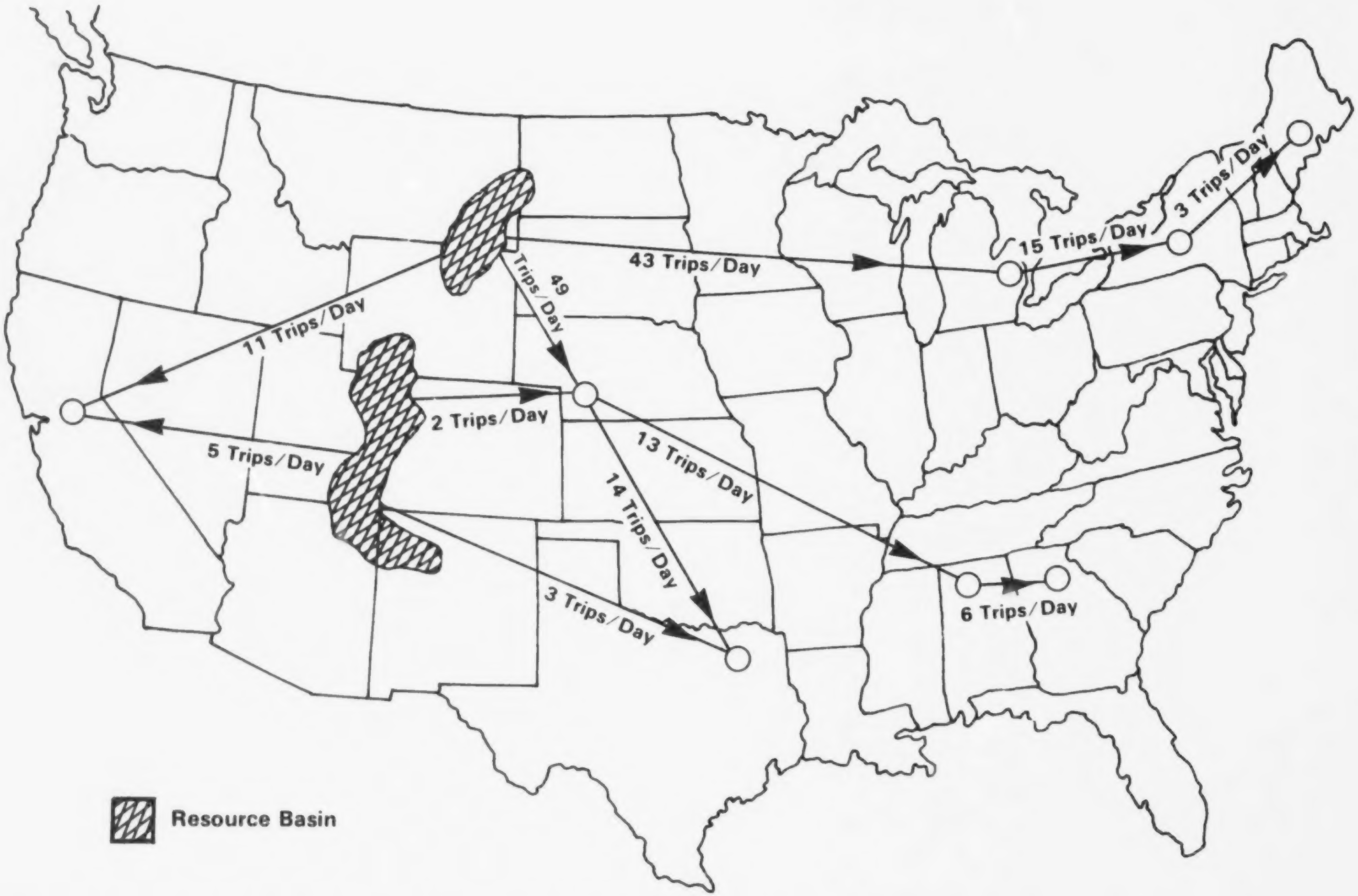
43 Trips/Day
15 Trips/Day
3 Trips/Day
49 Trips/Day
11 Trips/Day
2 Trips/Day
5 Trips/Day
13 Trips/Day
14 Trips/Day
3 Trips/Day
6 Trips/Day
Resource Basin

Figure 10. Unit coal energy to be transported from the Western United States by the year 2000. Source: Modified from University of Oklahoma and Radian Corporation (1977b).

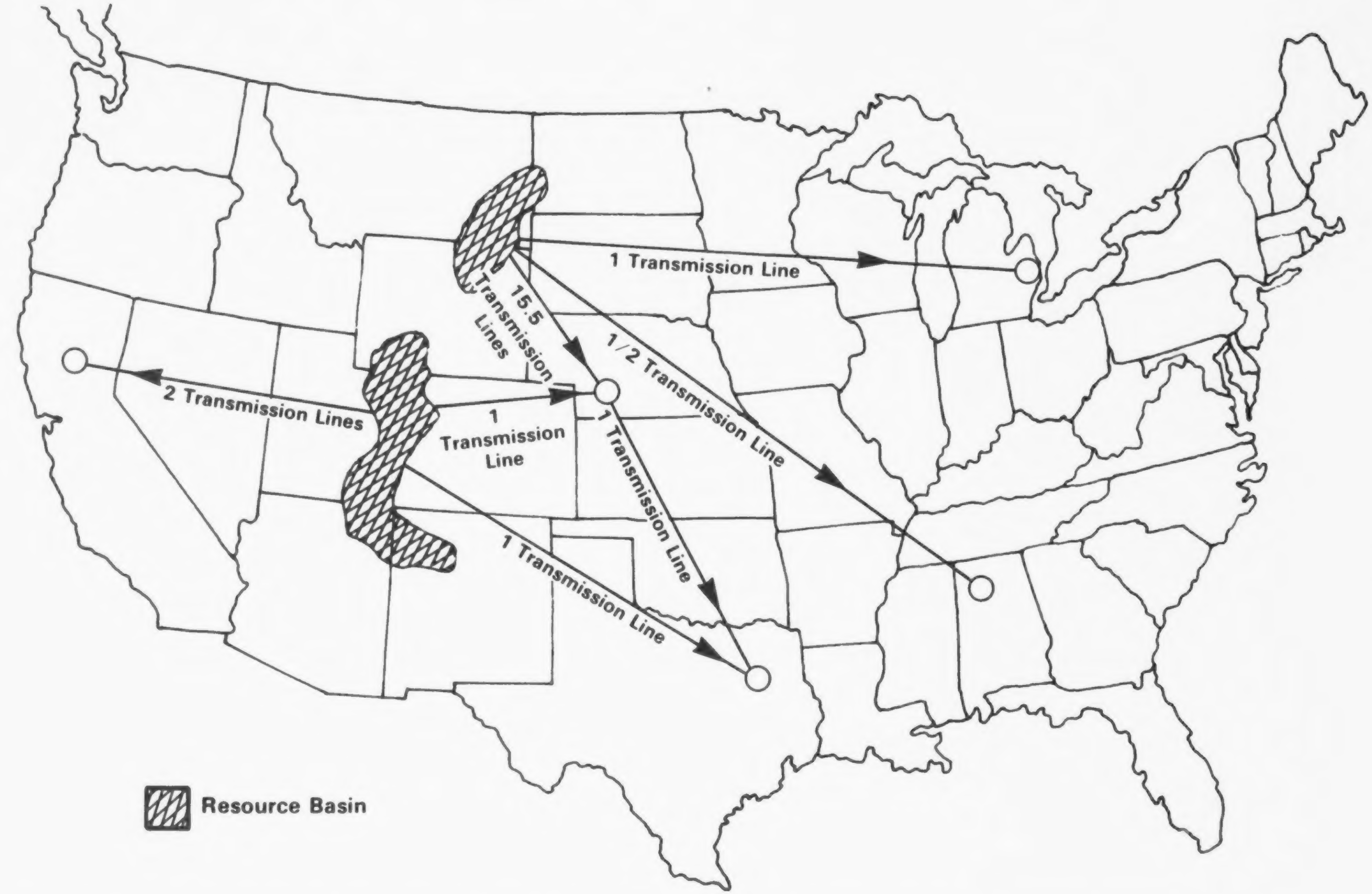
1 Transmission Line
15.5 Transmission Lines
1/2 Transmission Line
2 Transmission Lines
1 Transmission Line
1 Transmission Line
1 Transmission Line
Resource Basin

Figure 11. Electricity expected to be transported from the Western United States by the year 2000. Source: Modified from University of Oklahoma and Radian Corporation (1977b).

Gas and liquid fuels (crude oil, shale oil, and coal syncrude) from the western region will be transported via pipeline to major refinery regions (University of Oklahoma and Radian Corporation, 1977b). Existing trunkline capacity for gas and liquid fuels from the Northern Great Plains has been estimated at 28 million m^3/day and 98,000 m^3/day, respectively. Electrical transmission lines will distribute the necessary power both locally and nationally. Proposed powerplants at Colstrip, Gillette, and Sheridan will supply the needs of the local area and will increasingly supplement those needs of the Midwest, South and East. Presently, Colstrip is the major supplier of electrical power with lines going to Broadview, Montana, with relay to centers in the Northwest.

Whether coal, gasification, liquefaction, or electrical transmission are implemented, the right-of-way development will disturb several thousand square kilometers of land. By the year 2000 electrical transmission lines, which generally have 30 m right-of-way per side, will by themselves require 1,275 km^2 of land in the Tongue-Powder River study area (University of Oklahoma and Radian Corporation, 1977b).

6. OTHER SOURCES OF POLLUTION

EROSION

Erosion in the Tongue and Powder River Basins is dependent on several environmental factors, some of which vary through the year. Weather changes, topography of the area, types of soil, land use and management practices, and seasonal availability of a canopy protection of crops and pastureland all influence the degree of erosive action present (Northern Great Plains Resource Program, 1974). In the lower, more arid elevations of the basins, droughts are common and high temperatures result in desiccation of young seedlings. The sparse vegetative ground cover that results helps produce poor soils that contain little organic matter and are highly susceptible to wind erosion. At these lower elevations the effect of wind or water on the detachment and relocation of soil particles results in problem levels of suspended sediments in the Tongue and Powder Rivers.

Summer storms subject localized areas to intense precipitation. This rapidly exceeds the land's capacity to absorb the water and results in surface runoff, often in the form of flash floods. These events often cause major erosion and subject receiving waters to very high suspended sediment concentrations. In addition, these events may cause both major and minor "spills" of commercial chemical products.

Mining has increased erosion in the basins through such activities as removal of overburden material, stockpiling, and relocation of soil. Blasting increases the amount of dust suspended in the air, which, together with windblown coal dust and ash from transportation, storage, and disposal areas, might later settle in a waterway or reservoir (U.S. Geological Survey and Montana Department of State Lands, 1977). Other erosive mechanisms associated with mining include the continual traffic of large machinery and destruction of natural vegetative cover. Although agricultural activities pose a lesser erosive problem in the Tongue and Powder River Basins than mining, agricultural runoff is a source of nutrients, fertilizers, pesticides, and herbicides. Several cattle ranches in the basins have feedlot operations that impose an additional major runoff problem through the release of high concentrations of organic material to the drainage areas.

MINE DRAINAGE

Acid mine drainage, the biggest hazard of mining in the Eastern United States, is not expected to be a problem in the Tongue and Powder River Basins. The sulfur content of coal in this area is generally less than 1 percent, and there is little likelihood of significant acid formation when exposed deposits are brought into contact with air and water (Northern Great Plains Resource Program, 1974). The high alkalinity of ground water in the coal beds further helps to neutralize any acids that should flow through them (U.S. Bureau of Indian Affairs, 1974). However, runoff through natural and manmade waterways will carry essentially all the waste products of the mine into surrounding drainages. Interception of ground-water aquifers during the mining operations may also result in a net inflow and accumulation of water in the active pit; this water, when discharged, may become a water quality problem if it was in contact with low-grade coal adjacent to a coal seam that is high in sulfates or other uncommon leachates (Northern Great Plains Resource Program, 1974). Surface runoff, or shallow ground water such as that from irrigation return flows, may percolate through mine spoil areas resulting in increased salts, especially sulfates or heavy metals.

Potential sources of water quality contamination associated with mining activities include loading, crushing, and screening facilities, access and hauling roads, equipment maintenance and building areas, overburden removal and deposition, construction of water control facilities, and stream diversions. Total dissolved solids and suspended solids from erosion of the disturbed areas are the most obvious potential pollutants; however, a number of water quality parameters could be affected by coal mining activities, and contamination from oils and greases, antifreeze, detergents, and residuals from blasting agents are not uncommon (Northern Great Plains Resource Program, 1974).

URBAN RUNOFF

Rapid population growth can be expected in the Tongue and Powder River Basins as a consequence of increased energy development (University of Oklahoma and Radian Corporation, 1977c). The resultant buildup of communities will increase the contributions of nonpoint urban runoff to the basins in addition to augmenting the consumptive water demands and burden on existing sewage facilities. The communities of Miles City, Colstrip, Sheridan, and Gillette are among those expected to be particularly influenced by the growing mining industry throughout the study area.

Nonpoint urban runoff is produced by precipitation that washes a population center, flushing a great variety of city wastes into the nearest water system. The quality of this runoff is variable and unpredictable; however, it is typically high in nutrients and suspended sediments. Combined storm and domestic sewer overflow is a common urban source of organic pollution to the aquatic ecosystem. Animal wastes, fertilizers, pesticides, and general street debris are other common urban pollutants.

7. WATER REQUIREMENTS

WATER RIGHTS

The Northern Great Plains area, during the 19th century, adopted a laissez-faire philosophy toward water allocation and development (University of Oklahoma and Radian Corporation, 1977c). A traditional "senior take all" appropriation doctrine evolved in which the first individual to divert water to a beneficial use established a dated and quantified right to first use of the water. All stream users thus establish dated rights, and as water supplies decrease those bearing later priority dates are shut off until senior rights are met (Lord et al., 1975). In light of increasing population growth and water demands, however, Federal and State regulations to control use have been established; it is probable that legal rights to utilize water will become a major factor in regional decisions regarding future energy development in these areas.

The Yellowstone River Compact of 1950, which provides the basis for dividing water of the Yellowstone River between the States of Montana, Wyoming, and North Dakota, is the primary Federal law governing distribution of surface waters for the Tongue and Powder River Basins. In this law, those water rights and supplies established prior to 1950 are recognized as first priority (Missouri River Basin Commission, 1978a). The remaining unused and unappropriated waters are divided so that Wyoming is allotted 40 percent of the Tongue River flow and 42 percent of the Powder River, with the remainder going to Montana. Other major provisions of the act specify that the compact may not adversely impact any rights to the use of Yellowstone River Basin waters that are Indian owned nor may water be diverted outside of the Yellowstone Basin without unanimous permission of those States signing the compact (Missouri River Basin Commission, 1978a). The latter article has become highly controversial in recent years because industrial interests and the State of Wyoming would like to divert water out of the Yellowstone Basin for energy conversion purposes, while Montana's present position is to withhold approval of such diversions until agreement is reached as to the total quantity of water available for consumption by each State (Montana Department of Natural Resources and Conservation, 1976a). The compact contains no water quality provisions but rather relates strictly to diversion of Yellowstone River Basin waters.

In 1974, the Yellowstone Moratorium was enacted, which suspended for three years all large applications for water rights permits--i.e., those diversions greater than 0.57 m^3/sec or storage requests greater than 17 million m^3--in the Yellowstone River Basin (Montana Department of Natural Resources and Conservation, 1976a). Furthermore, the moratorium suspended any Federal reservations of water rights during that time and suspended six existing permit applications for industrial water use (Missouri River Basin Commission, 1978b). Over 30 permit applications were suspended during the period, many of which are in the Tongue-Powder River Basins examined in this report (Table 25). The purpose of the moratorium was to allow time to evaluate needs in the Yellowstone Basins for protection of existing and future beneficial water uses, including maintenance of minimum instream flow and reservation of water for agricultural and municipal demands (Montana Department of Natural Resources and Conservation, 1976a).

The Montana Department of Natural Resources and Conservation (1976a) states: "There is not enough water physically in the Yellowstone basin to satisfy all reservation requests that have been filed. In addition, due to legal difficulties, it is not presently known exactly how much unappropriated water is available." Disputes over water rights on Indian lands and Federal reservation land (such as National forests), as well as numerous claims by private individuals or agencies, are presently under litigation. The Montana Department of Natural Resources and Conservation (1976a) has proposed a number of options for distribution of the suspended water rights based upon the four major uses to which water would be put in this area: irrigation, municipal, energy conversion, and instream flows. Which of these options are finally decided upon will have a major impact on all future development in the Tongue and Powder River Basins.

WATER AVAILABILITY

Under the terms of the Yellowstone River Compact, continued diversion of water from the Tongue and Powder Rivers for consumptive use may continue in Wyoming and Montana so long as flow exists in the tributaries. The Wyoming State Engineer's Office has estimated that Wyoming's 40 percent allocation of the Tongue River, after subtracting supplemental irrigation rights and pre-1950 users, is approximately 119 million m^3/yr out of a total river average of 297 million m^3/yr (Montana Department of Natural Resources and Conservation, 1976a). The average annual quantity available for diversion in the Powder River Basin is estimated to be 354 million m^3/yr, of which Wyoming is entitled to 149 million m^3 (Missouri River Basin Commission, 1978a). Anticipated changes in surface water consumption of the Tongue and Powder River Basins by the State of Wyoming are shown in Table 26. In both Montana and Wyoming, additional storage facilities must be developed if any compact water for these two basins is to be actually available during drought years, assuming those pre-1950 rights are actually claimed.

The average annual discharge from the Tongue River, adjusted to 1975 level of development, is 387 million m^3; the maximum recorded runoff was 825 million m^3 in 1975, and the minimum recorded annual discharge was only 51 thousand m^3 in 1961 (Missouri River Basin Commission, 1978b). The average annual discharge of the Powder River, adjusted according to 1975 level of depletion, is 522 million m^3; maximum recorded runoff reached 1,453 million m^3 in 1944, and the minimum recorded annual discharge was 71 thousand m^3 in 1961 (Missouri River Basin Commission, 1978b). Table 27 shows the expected increases in water depletion for consumptive use by the year 2000, projected by the State of Montana at three possible levels of

TABLE 25. APPLICATIONS FOR RESERVATIONS OF WATER IN THE TONGUE, POWDER, ROSEBUD, SARPY, AND ARMELLS CREEK BASINS SUSPENDED BY THE YELLOWSTONE MORATORIUM IN MONTANA

Applicant	Source	Amount Requested	Use
Big Horn Conservation District	Bighorn River, Tongue River	4.28 m^3/sec:26.2 million m^3/yr	Irrigation (39.03 km^2)
Treasure Conservation District	Yellowstone and Bighorn Rivers, Sarpy and Tullock Creeks	3.65 m^3/sec:24.6 million m^3/yr	Irrigation (30.94 km^2)
Rosebud Conservation District	Yellowstone, Tongue Rivers, Armells, Rosebud Creeks	16.57 m^3/sec:116.1 million m^3/yr	Irrigation (151.19 km^2)
North Custer Conservation District	Yellowstone River, Tongue and Powder Rivers	20.74 m^3/sec:128.7 million m^3/yr	Irrigation (148.50 km^2)
Powder River Conservation District	Powder River, Tongue River, and various tributaries	16.52 m^3/sec:102.4 million m^3/yr	Irrigation (122.36 km^2)
Department of Natural Resources and Conservation	Tongue River	555.1 million m^3	Irrigation, industrial, and fish and wildlife
Department of Natural Resources and Conservation	Powder River and tributaries	1,418.5 million m^3	Irrigation, industrial, and fish and wildlife

Source: Modified from Montana Department of Natural Resources and Conservation (1976a).

TABLE 26. ANTICIPATED CHANGES IN SURFACE WATER DEPLETION LEVELS IN THE TONGUE AND POWDER RIVER BASINS, NORTHEAST WYOMING

River Basin and Use	Depletion ($m^3 \times 10^6$) 1985	2000
Tongue River Basin		
Irrigation	14.8	14.8
Municipal and domestic	0.4	0.5
Livestock	1.0	2.0
Energy	9.2	37.0
Total	25.4	54.3
Powder River Basin		
Irrigation	18.5	18.5
Municipal and domestic	0.2	0.4
Livestock	1.0	2.0
Energy	16.6	62.9
Total	36.3	83.8

Source: Modified from Missouri River Basin Commission (1978a).

development. It can be seen that at the high level of development, the total expected consumption of the Tongue River would be 201 million m^3/yr, and 222 million m^3/yr depletion in the Powder River. Within the region there is extreme variation in streamflow from year to year and from place to place. Although the maximum consumptive use values are well under the average annual flows for both rivers, they far exceed the minimum recorded discharges for

TABLE 27. ANTICIPATED LEVELS OF WATER DEPLETION FOR CONSUMPTIVE USE BY YEAR 2000 IN THE TONGUE AND POWDER RIVER BASINS

	Increase in Depletion (m^3 yr x 10^6)		
River Basin and Use	Low Level of Development	Intermediate Level of Development	High Level of Development
Tongue River Basin			
Irrigation	18.0	36.1	54.2
Energy	14.1	57.8	145.6
Municipal	negligible	0.4	1.0
Total	32.1	94.3	200.8
Powder River Basin			
Irrigation	61.8	123.7	185.5
Energy	1.1	23.3	34.7
Municipal	0.4	0.7	1.4
Total	63.3	147.7	221.6

Source: Modified from Montana Department of Natural Resources and Conservation (1977).

the basins. Flows in the basin areas may also fluctuate throughout a given year, and it is not unusual for perennial streams to contribute over 80 percent of their annual flow in the months of May, June, and July (U.S. Environmental Protection Agency, 1974). Certainly there will be times when adequate water supplies will exist to satisfy all consumptive demands. However, in planning for future development in the basins, it will be necessary to determine how much water can be reliably counted on as available throughout the year and from year to year.

TONGUE AND POWDER RIVER WITHDRAWALS

Energy Resource Development

Increased energy development in the Tongue and Powder River Basins will have a significant environmental impact, particularly on water resources of the region. Surface mining of the enormous coal reserves requires approximately 0.07 to 0.08 liters of water per kg of coal mined (Adams, 1975). Conversion of coal into electricity or into natural gas and crude oil requires large quantities of water. Transport of coal to powerplants, if done by coal slurry line, can require an additional 2.5 to 3.7 million m^3/yr of water to provide slurry to a 1,000 MW electric generating plant (Adams, 1975). These water demands are immense since many streams in the resource area are dry much of the year and ground-water supplies must be carefully mined to avoid depletion of usable aquifers at a rate in excess of recharge capacity. The total water consumption demands in the Tongue and Powder River Basins in Montana expected by the year 2000 (at maximum projected development levels) are shown in Table 28 (Missouri River Basin Commission, 1978b).

TABLE 28. WATER CONSUMPTION DEMANDS FROM ENERGY DEVELOPMENT ACTIVITIES EXPECTED IN THE TONGUE AND POWDER RIVER BASINS BY THE YEAR 2000 AT MAXIMUM PROJECTED DEVELOPMENT LEVELS

Development	Water Consumption ($m^3 \times 10^6$)
Mining	10.6
Reclamation or dust control	31.0
Coal gasification	74.0
Electric generation	17.5
Slurry pipeline	136.8
Total	269.9

Source: Modified from Missouri River Basin Commission (1978b).

For purposes of full-scale industrial development in the study basins, it is likely that transport of water via aqueducts will be more economical than transport of coal to the water sources, since coal beds subject to development lie from 32 to 322 km from major water supplies (U.S. Bureau of Reclamation, 1972). Coal beds along Sarpy and Rosebud Creeks are 32 to 64 km from the Yellowstone River, the most likely source of water. Beds in the Tongue River drainage are from 48 to 203 km, and those in the Powder River Basin in Montana are from 96 to 129 km from the Yellowstone River. The surface reserves imported from the Yellowstone are enough to adequately and inexpensively supply the Sarpy and Rosebud Creek area (U.S. Bureau of Reclamation, 1972); construction of large-capacity aqueducts from the Yellowstone and Bighorn Rivers to meet industrial demands would be more economical than construction of several smaller lines from lesser tributaries nearby.

It is predicted that diversion of up to 3.2 billion m^3/yr of water will be necessary to meet future mining industry demands throughout the Tongue and Powder River Basin study area (U.S. Bureau of Reclamation, 1972). An estimated 3.9 billion m^3 could be obtained from the Yellowstone River and its tributaries; such withdrawals would leave 2.1 billion m^3 in the Yellowstone during extreme low water years. During an average water year, the Yellowstone flow would equal 6.9 billion m^3 after meeting all existing water uses and after satisfying projected industrial water needs. Although it appears, then, that sufficient water will be available to meet all future municipal, industrial, and agricultural demands in the area, construction of a number of mainstem or offstream storage facilities would be necessary to assure an adequate, continuous water supply for anticipated energy developers (U.S. Bureau of Reclamation, 1972).

Irrigation

In the Upper Missouri Basin, agriculture, primarily irrigation, accounts for two-thirds of the surface water withdrawals and over 90 percent of the consumptive water use (Lord et al., 1975). In the Tongue and Powder River study areas, irrigation accounts for nearly all water diverted and consumed. Since 1971, irrigated agriculture in the Yellowstone Basin has been increasing, mainly as a result of the introduction of sprinkler irrigation systems (Montana Department of Natural Resources and Conservation, 1977).

In the State of Montana, approximately 7.32 km^2 of land in the Rosebud Creek Basin are irrigated, with 13.4 million m^3/yr of water diverted from the creek and 6.3 million m^3/yr consumed for these agricultural needs (Table 29). Over 230.3 million m^3/yr of water are diverted from the Tongue River to irrigate 126.18 km^2 of Montana land annually, with 108.5 million m^3/yr, or 47 percent, of that amount consumed (Montana Department of Natural Resources and Conservation, 1976a). The Powder River and Little Powder River provide 252.0 million m^3 and 50.2 million m^3/yr, respectively, for diversion to irrigate a total of 165.28 km^2 of land. Of these diversion figures, 118.4 million m^3 and 23.6 million m^3, respectively, are consumed (Montana Department of Natural Resources and Conservation, 1976a). The irrigation season typically extends from April through October, but over half of the required water is used in July and August.

TABLE 29. TONGUE AND POWDER RIVER BASIN WATERS USED FOR IRRIGATION IN MONTANA (1976)

Subbasin	Surface Area (km^2)	Total Annual Diversion (million m^3)	Total Annual Depletion (million m^3)
Little Powder River	27.46	50.2	23.6
Powder River	137.82	252.0	118.4
Tongue River	126.18	230.8	108.5
Rosebud Creek	7.32	13.4	6.3

Source: Modified from Montana Department of Natural Resources and Conservation (1976a).

Throughout the study area there exist numerous private irrigation diversions built on small storage facilities. In the Montana portion, over 100 smaller users have been issued water rights for irrigation (Montana State Engineers Office, 1978). Particularly in the Wyoming upstream reaches of the Tongue and Powder Rivers, there are abundant diversion ditches and livestock impoundments that somewhat regulate the tributary flows. These direct water into concrete drainage ditches, small coulees, and ponds for use. Irrigative systems such as flooding and center- and side-roll sprinklers are thus supplied with the water needed to irrigate (Toole, 1976).

The Tongue River Reservoir, built in the 1940's, has the largest storage capacity (85.6 million m^3) of any water body used for irrigation in the study basins. In Wyoming, upstream of the reservoir, 96 smaller users have been issued water rights for irrigation projects ranging from 0.02 to 2.67 km^2, with authorized diversions of from 0.06 to 14.3 million m^3/yr (Wyoming State Board of Control, 1972).

The Powder River currently has no irrigation projects of great size. In Wyoming, water rights have been issued to 75 appropriators for irrigation of land in the Powder River Basin, and to 17 individuals for irrigation in the Little Powder River Basin. These project requests range in size from 0.02 to 2.08 km^2 with authorized river diversions ranging from 0.06 to 6.6 million m^3/yr (Wyoming State Board of Control, 1972). In 1949, the Bureau of Reclamation initiated a project to create Moorhead Dam for expansion of irrigated lands in the Powder River Basin. However, the project was opposed by regional cattle owners since the flood waters of the dam would represent a reduction of approximately 60 km^2 of grazing lands (Personal communication, Glen Smith, Montana Department of Natural Resources, Helena, Montana, 1978) and, thus, was never completed.

It is expected that irrigation will continue to be the major water use in this study area even if future energy development should reach maximum projected levels. The Missouri River Basin Commission (1978a) reports that late-season water shortages as great as 89.4 million m^3 annually are already occurring in northeastern Wyoming. The problem is aggravated by high evaporation losses from the many irrigation reservoirs in the basins (Missouri River Basin Commission, 1978a) and could be expected to become more severe with increasing energy development activities that would rely on surface water supplies for support. Nevertheless, with the construction of additional large storage facilities, sufficient water should be available to support projected mining and coal conversion facilities without seriously jeopardizing agricultural water uses (Missouri River Basin Commission, 1978a). It should be pointed out that this approach considers only water quantity available for diversion, which is impacted by energy development activities. Industrial impact on water quality in the basins is discussed later in this report; nevertheless, it is notable that the Yellowstone-Tongue Areawide Planning Organization (1977) cites "even at the low projected level of development, the quality of the water Powder River would be unacceptable for irrigation at least one year out of two" as a result of industrial water withdrawals that aggravate the already excessive salinity levels.

Municipal and Industrial

There are a variety of additional requirements for water in the Tongue and Powder River Basins. These include domestic, manufacturing, governmental, and commercial needs. Although there are many municipal and industrial users in the study area (Tables 30 and 31), surface water consumption related to these systems is relatively minor (Montana Department of Natural Resources and Conservation, 1976a). The Missouri Basin Inter-Agency Committee (1971) reports that the entire Yellowstone River Basin, with approximately 291,000 public or private water systems, annually withdraws an average of only 50.6 million m^3 of water for municipal and rural domestic water use. An additional 129.5 million m^3/yr of Yellowstone River Basin water is consumed for industrial purposes (Missouri Basin Inter-Agency Committee, 1971). Water consumption for the Tongue and Powder River Basins alone is not known at this time.

In addition to the consumptive impact on usable water, pollutants associated with municipal and industrial return flow can substantially impact downstream users. Municipal areas in the Tongue and Powder Rivers utilize several waste water facilities to reduce this impact. The large towns generally are served by trickling filters, activated sludge, and oxidation ponds and ditches; smaller communities are usually served by private septic tanks for sewage disposal. Industrial dischargers within the basin areas are predominately associated with the food producing industry; packing plants, dairies, and sugar beet and potato processing are among the major industrial processors in the Northern Great Plains region (Northern Great Plains Resource Program, 1974). Although surface water withdrawal requirements are presently low in the study basins, future water requirements can be expected to increase as a result of population growth, especially in those areas with rapidly expanding energy development and mining activities. Most of the communities in the region have plans for larger replacement facilities to accommodate this anticipated growth (Yellowstone-Tongue Areawide Planning Organization, 1977). The Missouri River Basin Commission (1978a) reports that between the years 1975 and 2000, municipal and rural domestic water consumption in northeast Wyoming could increase 11.7 million m^3/yr, and industrial-related water consumption could increase 126.4 million m^3/yr. These increases would result in a total consumptive use of 24.0 million m^3/yr for municipal and domestic uses and 337.3 million m^3 for industrial use.

Fish and Wildlife

The allocation of water to fish and wildlife facilities in the study area will have to follow a coordinated comprehensive plan for the conservation, development, and management of the waters and related land resources in the Yellowstone, Tongue, and Powder River Basins if environmental objectives are to be met. Maintenance of minimum flows in the Tongue River is especially desirable because of the highly diverse and productive fishery found there. However, the Montana Department of Natural Resources and Conservation (1976a) reports that at present there exists no legal obligation to meet this need. Therefore, from the standpoint of fish and wildlife objectives, the foremost need is for environmental legislation at the State level (Missouri River Basin Commission, 1978a).

TABLE 30. DOMESTIC WASTE TREATMENT FACILITIES IN THE TONGUE AND POWDER RIVER BASINS

Source and Location	Existing Treatment	Receiving Waters
Midwest (AMOCO)	A. Gas plant camp septic tank/leach field	A. Castle Creek
	B. Town-0.02 km^2 lagoon	B. Salt Creek
Ranchester	2-cell lagoon	Tongue River
Sheridan	High-rate trickling filter	Goose Creek
Wyoming Soldiers and Sailors Home, Buffalo	Imhoff tank/trickling filter	Clear Creek
Buffalo	0.07 km^2 lagoon	Clear Creek
Dayton	2 0.01 km^2 lagoons	N/A
Edgerton	2 0.01 km^2 lagoons	N/A
Kaycee	A. 0.02 km^2 lagoon	A. Middle Fork Powder River
	B. 3-unit trailer court septic tank	B. Unnamed Draw
Bear Lodge Resort, Sheridan County	Extended aeration 2 polishing ponds	Little Willow Creek
V.A. Hospital, Sheridan	Trickling filter	Goose Creek
Linch	A. 2 lagoons, 0.01 km^2	N/A
	B. Septic tank system-100 people serviced	N/A
Clearmont	2 lagoons	N/A
Skelly Truck Stop, Sheridan	Septic tank	Goose Creek
Broadus	Secondary stabilization pond	Powder River
Forsyth	Secondary stabilization pond	Yellowstone River
Lame Deer	Secondary stabilization pond	Deer Creek

Source: Modified from Missouri River Basin Commission (1978a).

TABLE 31. INDUSTRIAL DISCHARGERS IN THE TONGUE AND POWDER RIVER BASINS, NORTHEASTERN WYOMING

User	Receiving Stream	Waste Discharge Characteristics
Continental Oil Company Sussex Gasoline Plant, Linch	Meadow Creek	Cooling water
Mullinax Concrete Company, Sheridan	Goose Creek	Gravel wash water
Buffalo Sand and Gravel	Unnamed draw to Goose Creek	Occasional wash water discharged into natural drainage
Bighorn Coal Company, Sheridan	Goose Creek	Strictly pit water discharged into natural drainage
Carter Oil Company, Gillette	Little Powder River	Pit water

Source: Modified from Missouri River Basin Commission (1978a).

Water allocations for fish and wildlife go to refuges, wetlands, management areas, fish hatcheries, fish impoundments, and maintenance of instream flows. The Missouri Basin Inter-Agency Committee (1971) has projected that in the entire Missouri River Basin, from 1980 to 2000, surface water depletions associated with wetlands and fish and wildlife will increase from 218.3 million m^3 to 578.5 million m^3 above present levels of consumption. It is not known at this time what present levels of consumption related to fish and wildlife are in the Missouri River Basin, nor is that information available for the individual basins under study in this report. At any rate, fish and wildlife are relatively small water "consumers," and most water depletions can be attributed to hatchery facilities.

Bovee et al. (1977) have demonstrated that consideration of a single instream use as the basis for a flow recommendation is inadequate. Methodologies have been developed for measurement of a variety of instream parameters in the Tongue River. These parameters include sediment transport, mitigation of adverse impacts of ice, evapotranspiration loss, and fisheries maintenance including spawning, rearing, and food production. Bovee's field tests indicate that flow requirements for any particular fishery use vary in importance throughout the year. In the Tongue River, it was recommended that during the month of June a base flow of at least 23.6 m^3/sec must be maintained to initiate sediment scour from pools, to provide spawning habitat for the shovelnose sturgeon, and to accommodate evaporative and transpiration losses from the river (Bovee et al., 1977). In early February, a base flow of 3.85 m^3/sec would be sufficient to provide habitat for fish-rearing activities and insect fauna, as well as to prevent loss of habitat as a result of ice formation. The EPA suggests that in late February, the Tongue River flow should be increased to 12 m^3/sec to facilitate ice breakup; following breakup a return to the 3.85 m^3/sec level would be adequate until summer spawning season begins (Bovee et al., 1977).

Minimum annual runoff levels requested by the Fish and Game Commission in Montana for a number of tributaries in the study area are shown in Table 32. These recommended values are considered to be barely sufficient to satisfy instream flow requirements during the low water months of July through September. The Montana Department of Natural Resources and Conservation (1976a) notes, however, that if all Fish and Game instream recommendations were implemented in Otter, Pumpkin, and Hanging Woman Creeks there would be little surplus water left for other uses. This suggestion was also made by Shupe (1978), who conducted a study of proposed instream flow requirements and potential reservoirs in the Powder River. He suggested that instream flow requirements for continuous discharge of a portion of the storage capacity of reservoirs reduced water availability for industrial use from 53 to 86 percent. An assessment of the planned Middle Fork (of the Powder River) Reservoir revealed that, with all instream flow requirements active, the reservoir would operate at near empty levels much of the time and would provide less than half the water annually for diversion that would be available without instream flow criteria (Shupe, 1978). Thus, the recognition of valid instream flow water rights may play a large role in limiting growth of energy resource development in the Tongue and Powder River Basins.

Livestock

Livestock account for a substantial portion of the agricultural-related water use in the Tongue and Powder River Basins. Table 33 shows the 1965 level of consumptive and evaporative losses associated with livestock facilities in the Yellowstone Basin, as well as projected consumption levels to the year 2020. Surface water supplies can be expected to continue to satisfy most livestock demands in this area; the Missouri Basin Inter-Agency Committee (1971) reports that 58 percent of the 1965 livestock water demands were met by surface water and projects that by the year 2000 surface water resources will supply 64 percent of the areal livestock needs.

WATER AVAILABILITY VERSUS DEMAND

The State of Montana has been authorized 60 percent of the annual runoff of the Tongue River Basin and 58 percent of surface water discharges from the Powder River as part of the Yellowstone River Compact. At present, disagreement still exists as to the actual amount of water reliably available for depletion in either basin by the States of Montana and Wyoming; nevertheless, water demands in the study area are currently being met with existing surface and ground-water supplies.

TABLE 32. MINIMUM ANNUAL INSTREAM FLOW REQUIREMENTS REQUESTED BY THE MONTANA FISH AND GAME COMMISSION FOR A NUMBER OF TRIBUTARIES IN THE POWDER RIVER STUDY AREA

Tributary	Annual Stream Runoff Requirement ($m^3 \times 10^6$)
Rosebud Creek	14.1
Tongue River	299.8
Hanging Woman Creek	2.3
Otter Creek	2.4
Pumpkin Creek	9.0

Source: Modified from Montana Department of Natural Resources and Conservation (1976a).

The expansion of industry will put increasing stress on the existing water resources in the basins, and State planning is underway to assure that minimum stream flows are maintained during low water years. All water rights applications that have been suspended since 1974 by the Yellowstone Moratorium are now being considered, and a number of possible alternatives for distributions of future water rights have been proposed (Montana Department of Natural Resources and Conservation, 1976b). Whatever final decisions regarding future developments are reached, however, additional water storage to regulate the highly unpredictable river flows in the study area will be necessary to provide reliable year-round water resources.

TABLE 33. PROJECTED AVERAGE ANNUAL LIVESTOCK WATER USE IN THE YELLOWSTONE RIVER BASIN

Year	Source Surface Water (percent)	Source Ground Water (percent)	Number of Stock ponds	Water Depletion Evaporation (million m^3)	Water Depletion Livestock Consumption (million m^3)
1965	58	42	14,000	85	24
1980	61	38	19,000	104	38
2000	64	36	24,000	119	54
2020	63	37	25,000	104	75

Source: Modified from Missouri Basin Inter-Agency Committee (1971).

8. WATER QUALITY

SOURCES OF DATA

Available water quality information was used to assess the impact of existing energy developments and irrigation projects in the Tongue and Powder River Basins and to provide baseline data for determining the impact of proposed developments. Most of the water quality data contained in this report were obtained through the U.S. Environmental Protection Agency's computer-oriented system for STOrage and RETrieval of water quality data (STORET). Other sources of information include government documents and environmental impact statements. Physical and chemical data evaluated were primarily from U.S. Geological Survey stations (Tables 34 through 36, Figure 12). Some data collected by the U.S. Forest Service (Tables 35 through 36) were considered; however, these data were largely incomplete and provided little supplemental information to the USGS generated STORET data.

SUMMARY OF PHYSICAL AND CHEMICAL DATA

Summarized data for selected parameters are included in Appendix B. These data are organized by parameter, station number, and year for the period of 1970-77. Station number assignments in the Appendix tables, as well as on figures in this report, are based upon the last five numerals of the station STORET codes (Tables 34 through 36).

In Appendix B, data from 43 USGS stations in the Sarpy, Armells, Rosebud, Tongue, and Powder River Basins are presented. In general, for any given parameter, the annual arithmetic mean for that parameter at each station is presented, along with the annual minimum and maximum values and number of samples collected. It should be noted that no attempt was made to verify data retrieved from STORET; all parameter measurements were accepted at face value with the exception of those data that were obviously impossible and were thus deleted. No summary tables were prepared from the limited USFS data available in STORET for this area.

IMPACT OF DEVELOPMENT ON SURFACE WATER

Salinity

The Salinity Problem--

Salinity, the total concentration of ionic constituents, is the major water quality parameter of concern in the Tongue and Powder River Basins. Two processes contribute to increases in salinity--salt loading and salt concentrating. Salt loading, the addition of salts to the water system,

TABLE 34. U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN SARPY, ARMELLS, AND ROSEBUD CREEKS

STORET Number	Station Name	Latitude/Longitude
06294940	Sarpy Creek near Hysham, MT	46°14'12"/107°08'03"
06294980	East Fork Armells Creek near Colstrip, MT	45°58'42"/106°38'38"
06294995	Armells Creek near Forsyth, MT	46°14'59"/106°48'22"
06295250	Rosebud Creek near Colstrip, MT	45°46'03"/106°34'10"
06295350	Greenleaf Creek near Colstrip, MT	45°48'57"/106°25'08"
06295400	Rosebud Creek above Pony Creek, MT	45°53'33"/106°24'03"
06295500	Rosebud Creek near Rosebud, MT	46°06'46"/106°27'08"
06296003	Rosebud Creek at mouth, near Rosebud, MT	46°15'53"/106°28'30"

TABLE B29. CHLORIDE (mg/1), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	51(7-92)12	50(12-87)10	61(27-96)12	40(6-80)12	43(10-78)12	46(8-85)8	47(6-96)90
1300	109(49-165)10	123(38-230)8	141(88-280)8	148(64-230)8	96(35-200)10	134(37-200)5	119(30-580)73
1340	1459(368-1780)12	1357(370-1700)10	1318(1100-1600)12	1201(760-1400)12	975(130-1600)11	1077(420-1300)9	1238(130-1780)90
1350	--	--	--	--	560(-)1	640(310-970)2	613(310-970)3
1640	15(7-32)10	13(5-25)8	11(4-16)11	8(4-16)12	8(2-14)13	13(5-46)8	10(2-46)85
1700	280(53-728)30	261(160-360)7	343(61-543)11	268(11-450)14	224(97-390)13	289(79-540)9	261(11-728)108
2020	--	--	--	5(4-5)2	4(2-7)13	5(2-7)14	4(4-5)4
2040	--	--	--	5(5-6)2	4(2-6)10	5(2-8)11	5(5-6)4
2350	--	--	--	3(1-5)7	2(1-4)13	2(2-4)12	2(2-2)3
2400	5(1-14)10	5(4-7)9	4(2-7)11	4(2-7)12	4(2-9)15	7(2-16)7	5(1-16)87
2450	159(49-248)5	84(10-190)10	110(7-180)12	131(45-230)14	142(0-320)12	154(57-270)12	290(180-200)2
2492	--	--	--	2(-)1	10(6-16)3	6(4-7)2	7(2-16)6
2497	--	--	--	9(6-15)14	11(4-24)39	9(4-15)19	15(12-20)3
2605	--	--	--	28.5(28-29)2	17(4-26)6	32(18-61)4	24(4-61)12
2620	--	--	--	9(9-10)2	9(6-12)10	9(8-9)5	9(6-12)17
2630	--	--	--	12(11-13)3	5(3-10)6	7(2-15)7	7(2-15)16
2650	--	--	143(130-150)3	106(31-220)12	96(23-190)12	122(48-190)11	110(23-220)38

*For full description of station locations, see Table 36.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B30. DISSOLVED SILICA (mg/1), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	9(6-11)12	9(4-11)10	9(7-13)12	10(7-11)12	8(4-12)12	8(6-11)12	9(6-10)12	8(5-12)8	9(4-13)90
1300	9(5-14)10	8(1-11)8	9(7-13)11	9(4-11)13	9(8-10)8	8(5-9)8	7(1-11)10	7(5-9)5	8(1-14)73
1340	22(10-27)12	22(10-30)10	20(10-27)12	18(12-24)12	22(16-26)12	20(14-26)12	20(9-32)11	21(10-29)9	21(9-32)90
1350	--	--	--	--	--	--	15(-)1	15(11-19)2	15(11-19)3
1640	6(3-11)10	9(3-12)8	10(5-15)12	9(4-12)11	6(1-13)11	10(3-14)12	8(0-12)13	6(3-9)8	8(0-15)85
1700	9(6-15)30	9(6-13)7	10(7-16)12	9(6-12)12	9(6-13)11	9(7-13)14	9(7-13)13	9(5-14)9	9(5-16)108
2020	--	--	--	--	--	11(11-11)2	10(8-13)13	10(7-14)7	13(11-15)4
2040	--	--	--	--	--	9(9-10)2	8(6-11)10	8(4-14)11	14(12-14)4
2350	--	--	--	--	--	5(3-8)7	7(3-11)13	9(5-12)12	12(11-12)3
2400	8(2-11)10	8(4-12)9	8(3-14)12	8(3-13)11	7(2-13)11	7(1-11)12	7(1-12)15	7(2-12)7	7(1-14)87
2450	--	--	6(-)1	--	6(4-10)12	7(3-12)14	7(5-10)12	8(3-12)12	13(13-13)2
2492	--	--	--	--	--	7(-)1	10(6-17)3	4(2-6)2	7(2-17)6
2497	--	--	--	--	--	10(6-12)14	6(4-11)39	8(6-15)19	14(12-15)3
2605	--	--	--	--	--	12(8-16)2	11(0-22)6	19(8-39)4	14(0-39)12
2620	--	--	--	--	--	15.5(15-16)2	10(5-15)10	15(11-18)5	12(5-18)17
2630	--	--	--	--	--	4(1-7)3	5(2-8)6	6(3-10)7	5(1-10)16
2650	--	--	--	--	8(6-10)3	9(5-12)12	8(6-11)12	10(7-13)11	9(5-13)38

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B31. TOTAL HARDNESS ($CaCO_3$, mg/1), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	457(198-611)12	438(170-580)10	512(280-613)12	434(210-580)12	427(180-670)12	387(160-520)8	444(160-670)90
1300	1206(961-1630)10	1210(730-1600)8	1181(960-1400)8	1112(770-1500)8	956(650-1200)10	932(470-1200)5	1083(470-1630)73
1340	426(250-572)12	561(340-970)10	348(260-510)12	390(200-640)12	423(300-690)11	417(240-670)9	446(200-970)90
1350	--	--	--	--	620(-)1	460(400-520)2	513(400-620)3
1640	1029(430-2200)10	936(260-1800)8	774(180-1300)11	603(210-1100)12	561(240-820)13	708(310-1100)8	726(180-2200)85
1700	696(370-1060)30	608(400-750)7	743(509-1200)11	607(270-920)14	659(420-830)13	582(310-840)9	655(270-1200)108
2020	--	--	--	430(400-460)2	320(130-490)13	422(85-590)14	400(350-480)4
2040	--	--	--	490(440-540)2	393(190-630)10	535(120-750)11	495(480-540)4
2350	--	--	--	230(49-320)7	189(72-350)13	240(90-320)12	253(250-260)3
2400	515(114-860)10	582(310-830)9	412(160-510)11	421(91-600)12	443(130-760)15	540(210-660)7	470(91-860)87
2450	652(296-1110)12	535(260-790)10	507(320-660)12	540(230-770)14	531(190-850)12	661(400-930)12	690(630-750)2
2492	--	--	--	929(-)1	1210(630-1700)3	310(260-360)2	863(260-1700)6
2497	--	--	--	795(490-1300)14	861(210-1500)39	644(220-1300)19	890(680-1000)3
2605	--	--	--	2350(2300-2400)2	1650(1200-2200)6	1575(1100-2100)4	1741(1100-2400)12
2620	--	--	--	665(650-680)2	586(240-800)10	698(640-740)5	628(240-800)17
2630	--	--	--	366(270-470)3	214(59-459)6	163(40-330)5	228(40-470)14
2650	--	--	569(509-679)3	479(270-690)12	508(180-730)12	569(370-730)11	521(180-730)38

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B32. TOTAL IRON (μg/1), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	85(10-260)12	211(0-100)7	--	--	--	--	69(0-260)19
1300	124(40-270)10	102(20-280)6	--	4615(30-9200)2	208130(620.0-810000)4	108167(1500-230,000)3	--
1340	118(10-350)12	164(40-510)7	--	--	87280(5500-400,000)5	62400(1700-230,000)4	3800(-)1
1350	--	--	--	--	1900(-)1	8500(-)1	5200(1900-8500)2
1640	121(50-219)9	158(90-260)5	--	--	5200(-)1	1100(-)1	511(50-5200)16
1700	127(20-310)9	174(40-280)5	--	--	31(-)1	--	--
2020	--	--	--	--	288(90-680)5	435(130-1200)4	450(-)1
2040	--	--	--	--	816(180-1900)5	645(160-1200)4	950(-)1
2350	--	--	--	390(140-880)3	256(20-500)5	485(140-940)4	--
2400	121(40-230)10	197(100-270)6	--	--	604(350-1200)5	5585(300-21000)4	1227(40-21000)27
2450	--	--	7500(2000-13000)2	--	17525(2100-30000)4	560(-)1	--
2492	--	--	--	3100(-)1	1002(310-1300)4	8100(-)1	2235(310-8100)6
2497	--	--	--	2398(280-4000)12	6719(230-63000)11	15781(370-45000)7	--
2605	--	--	--	260(-)1	560(180-940)2	--	460(180-940)3
2620	--	--	--	280(-)1	612(360-990)4	--	546(280-990)5
2630	--	--	--	530(380-680)2	1090(780-1400)2	40500(7000-74000)2	14040(380-74000)6
2650	--	--	15000(-)1	68150(1600-170000)4	44550(2200-73000)4	85905(920-300000)4	62263(920-300000)13

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B33. TOTAL MANGANESE (μg/1), 1975-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1300	100(10-190)2	2865(100-11000)4	2657(70-5200)3	2181(10-11000)9
1340	--	1444(130-6400)5	955(50-3300)4	1227(50-6400)9
1350	--	150(-)1	160(-)1	155(150-160)2
1640	--	190(-)1	110(-)1	150(110-190)2
1700	--	5000(-)1	--	5000(-)1
2020	--	42(30-60)5	78(30-150)4	60(-)1
2040	--	94(50-190)5	95(60-130)4	90(-)1
2350	47(40-60)3	26(10-40)5	58(30-100)4	--
2400	95(20-170)2	64(30-90)5	147(30-420)4	100(20-420)11
2450	528(20-1400)4	312(50-550)4	9700(-)1	--
2492	150(-)1	122(60-230)4	100(-)1	123(60-230)6
2497	249(160-570)12	212(80-620)11	584(100-1400)7	--
2605	70(-)1	3580(60-7100)2	--	2410(60-7100)3
2620	280(-)1	900(150-1700)4	--	776(150-1700)5
2630	55(40-70)2	120(-)2	530(90-970)2	235(40-970)6

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B34. TEMPERATURE (°C), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	9.1(0-25.0)12	12(0-25.5)10	11.4(0-27.5)12	10.1(0.5-23.0)12	8.3(0-19.5)12	8.5(0-19.0)11	10.0(0-28)93
1300	10.5(0-27.0)10	8.7(0-32)8	8.8(0-29.0)8	10.8(0-31.5)8	8.8(0-22.5)10	5.9(0-20.0)9	0(0-0)2
1340	10.1(0-28.0)12	14.4(0-27.0)10	10.6(0-25.5)12	11.7(0-28.5)12	12.3(0-25.0)21	10.6(0-23.0)13	11.8(0-31.0)104
1350	--	--	--	--	19(-)1	14.2(3.5-25.0)2	15.8(3.5-25.0)3
1640	7.5(0-19.0)9	13.7(0-23.0)7	10.2(0-26.5)11	10.2(0-25.5)12	12.2(0-25.5)11	14.6(0-25.0)7	10.5(0-27)80
1700	10.7(0.5-25.0)18	12.5(0-26.0)18	9.6(0-31.5)14	12.6(0-28)13	13.9(0-27.0)18	11.1(0-27.0)18	11.4(0-31.5)127
2020	--	--	--	2.5(2.0-3.0)2	9.7(0-23.0)17	9.6(0-24.0)14	0(-)4
2040	--	--	--	1.8(1.5-2.0)2	14.2(0.5-24.0)11	11.3(0-23.0)13	0(-)4
2350	--	--	--	14.5(2.0-21.5)8	11.2(0.5-23.0)13	9.8(0-22.0)14	0(-)4
2400	6.8(0-21.0)9	13.1(0-29.0)8	10.3(0-26.0)11	5.2(0-27)133	12.5(0-26.0)22	11.3(0-26.0)12	7.4(0-29.0)218
2450	9.6(0-24.0)21	10.5(0-28.5)25	12.2(0-24.5)12	6.8(0-23.0)19	10.5(0-24.5)12	10.0(0-23.5)13	0(-)2
2492	--	--	--	18(-)1	15.3(5.0-24.5)5	19.3(18.0-22.0)3	16.9(5.0-24.5)9
2497	--	--	--	13.6(0-27.0)20	13.1(0-26.5)32	13.0(0-22.0)20	0(-)3
2605	--	--	--	1.2(0.5-2.0)2	8.9(0-22.5)6	6.0(0-14.5)4	6.7(0-22.5)12
2620	--	--	--	3.0(2.0-4.0)2	14.2(1.0-29.5)10	6.5(0-19.5)5	10.6(0-29.5)17
2630	--	--	--	1.5(0-4.5)3	16.1(0-27.5)6	8.4(0-26.5)7	10.0(0-27.5)16
2650	--	--	6.6(0-16.0)4	8.3(0-23.5)13	8.0(0-21.0)12	13.4(0-25.5)11	9.4(0-25.5)40

*For full description of station locations, see Table 36.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B35. DISSOLVED OXYGEN (mg/1), 1972-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	--	11.8(11.2-12.4)3	8.6(6.4-10.6)12	9.7(6.9-12.0)12	9.7(7.5-12.5)12	10.0(7.8-12.8)11	9.6(6.4-12.8)50
1300	--	--	--	9.9(7.6-11.6)3	9.8(7.5-12.8)10	10.4(7.4-12.9)7	10.0(7.4-12.9)20
1340	--	--	--	9.6(-)1	7.9(4.2-10.2)9	6.4(0.7-10.6)13	7.2(0.7-10.6)23
1350	--	--	--	--	8.3(-)1	9.6(8.2-11.0)2	9.2(8.2-11.0)3
1640	--	--	--	--	6.6(-)1	10.3(9.4-11.2)2	9.1(6.6-11.2)3
1700	10.8(8.8-12.8)2	7.2(4.5-10.2)3	7.2(5.6-9.1)5	7.8(2.9-11.1)5	7.5(5.6-10.4)5	8.6(7.4-10.3)4	7.9(2.9-12.8)24
2020	--	--	--	11.8(10.8-12.8)2	9.8(8.5-11.4)13	10.4(9.0-11.4)14	10.5(8.8-11.8)4
2040	--	--	--	10.8(9.8-11.8)2	9.2(8.2-13.1)10	10.1(8.9-11.8)12	11.1(9.0-13.2)4
2350	--	--	--	8.8(7.1-11.6)8	9.8(8.3-11.2)13	9.8(8.3-11.0)13	11.0(10.4-12.8)4
2400	--	--	9.8(8.0-12.0)8	10.0(7.2-11.6)12	9.4(7.7-12.8)12	10.0(8.0-12.5)12	9.8(7.2-12.8)44
2450	6.8(3.0-9.2)7	--	9.9(7.6-12.6)11	8.8(4.6-12.8)15	9.3(7.1-11.7)12	9.0(6.0-12.0)12	8.2(7.5-8.9)2
2492	--	--	--	9.6(-)1	9.3(9.2-9.5)2	7.5(6.9-8.1)2	8.7(6.9-9.6)5
2497	--	--	--	8.8(6.0-10.9)14	8.4(6.1-11.2)29	8.9(6.8-12.2)18	12.2(11.6-13.2)3
2605	--	--	--	7.5(1.4-13.6)2	6.7(0-14.4)6	6.9(0-11.4)4	6.9(0-14.4)12
2620	--	--	--	9.0(8.5-9.4)2	8.2(6.0-11.1)10	6.1(3.0-9.4)5	7.7(3.0-11.1)17
2630	--	--	--	12.0(10.0-13.2)3	9.0(6.8-11.8)6	9.7(5.2-12.0)7	9.8(5.2-13.2)16
2650	--	--	11.4(10.8-11.9)3	9.3(2.7-12.5)12	10.3(7.1-15.7)12	8.4(6.6-10.7)11	9.5(2.7-15.7)38

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B36. pH, 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	7.9(7.3-8.3)12	7.9(7.6-8.2)10	8.1(8.0-8.3)9	7.9(-)1	--	--	8.0(7.3-8.5)56
1300	7.8(7.2-8.2)10	7.9(7.6-8.1)8	8.0(7.9-8.2)6	8.3(8.2-8.5)3	8.0(7.7-8.2)10	8.0(7.8-8.3)6	8.0(7.2-8.5)67
1340	8.0(7.5-8.5)12	7.9(7.5-8.1)10	8.2(8.0-8.4)9	8.4(-)1	8.2(7.9-8.4)10	8.2(7.7-8.9)13	8.1(7.5-8.9)79
1350	--	--	--	--	8.2(-)1	8.2(8.0-8.4)2	8.2(8.0-8.4)3
1640	7.9(7.1-8.4)10	7.8(7.3-8.1)8	8.1(7.7-8.4)8	--	8.2(-)1	8.4(8.2-8.5)2	8.0(7.1-8.5)52
1700	8.0(7.5-8.2)30	8.0(7.7-8.1)7	7.9(7.5-8.2)8	--	7.9(-)1	8.8(-)1	8.0(7.2-8.8)76
2020	--	--	--	8.1(8.1-8.2)2	8.1(7.6-8.6)13	8.1(7.5-8.9)14	7.6(7.4-7.7)4
2040	--	--	--	8.0(8.0-8.1)2	8.0(7.5-8.2)10	8.1(7.5-8.7)12	7.6(7.4-7.9)4
2350	--	--	--	8.2(7.6-9.2)8	7.9(7.3-8.5)13	8.0(7.6-8.6)13	7.7(7.4-8.0)4
2400	7.9(7.2-8.4)10	8.0(7.6-8.3)9	8.0(7.6-8.4)11	8.0(7.7-8.5)12	8.1(7.8-8.4)12	8.1(7.7-8.5)12	8.0(7.2-8.5)89
2450	8.0(7.4-8.5)12	8.0(7.5-8.5)12	8.2(7.6-8.6)12	8.0(7.5-8.6)15	8.1(7.7-8.4)12	8.2(7.7-8.5)11	7.7(7.7-7.7)2
2492	--	--	--	8.5(-)1	8.4(8.2-8.8)4	7.7(7.0-8.4)2	8.2(7.0-8.8)7
2497	--	--	--	8.4(7.7-8.7)14	8.2(7.5-8.8)38	7.9(7.5-8.2)18	7.9(7.6-8.0)3
2605	--	--	--	7.8(7.5-8.0)2	7.8(7.5-8.1)6	7.5(7.1-7.9)4	7.7(7.1-8.1)12
2620	--	--	--	7.8(7.7-7.8)2	8.0(7.6-8.3)10	7.8(7.5-8.2)5	7.9(7.5-8.3)17
2630	--	--	--	8.5(8.3-8.6)3	8.0(7.5-8.7)6	8.3(8.0-8.7)7	8.2(7.5-8.7)16
2650	--	--	8.4(8.2-8.5)3	8.2(7.7-8.5)12	8.2(7.7-8.4)12	8.3(7.8-8.5)11	8.2(7.7-8.5)38

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B37. TOTAL ALKALINITY ($CaCO_3$, mg/1), 1970-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1970	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
1250	190(143-230)12	181(100-220)10	178(98-235)12	172(103-194)12	194(138-231)12	180(107-221)12	171(107-230)12	174(82-230)12	180(82-235)90
1300	175(110-267)10	172(117-283)8	144(85-230)11	142(101-185)13	164(138-205)8	165(75-279)8	160(107-238)10	157(123-189)5	158(75-283)73
1340	556(326-695)12	530(271-783)10	601(358-993)12	717(491-968)12	900(646-1160)12	756(591-943)12	519(180-820)11	602(344-787)9	653(180-1160)90
1350	--	--	--	--	--	--	346(-)1	420(300-540)2	395(300-540)3
1640	208(115-307)10	208(98-340)8	179(61-289)12	181(132-231)11	207(98-295)11	180(98-246)12	171(90-254)13	192(123-303)8	189(61-340)85
1700	200(121-300)30	221(155-350)7	229(143-386)12	211(119-300)12	282(123-509)11	251(123-476)14	227(141-369)13	245(156-394)0	228(119-509)108
2020	--	--	--	--	--	191(177-205)2	143(67-215)13	177(42-240)14	182(170-210)4
2040	--	--	--	--	--	214(198-231)2	172(104-270)10	214(57-290)11	212(210-220)4
2350	--	--	--	--	--	141(35-180)7	129(62-198)11	172(69-245)12	183(180-190)3
2400	108(67-250)10	214(135-252)9	175(80-260)12	192(79-240)11	183(90-217)11	175(50-221)12	178(74-254)15	217(123-271)7	186(50-271)87
2450	263(184-331)5	--	116(84-149)2	--	216(110-288)12	225(118-350)14	212(167-299)12	228(120-354)12	325(300-350)2
2492	--	--	--	--	--	372(-)1	306(226-358)3	150(90-210)2	265(90-372)6
2497	--	--	--	--	--	344(142-463)14	293(262-500)19	274(98-519)19	430(340-480)3
2605	--	--	--	--	--	490(439-540)2	404(235-625)6	449(250-828)4	433(235-828)12
2620	--	--	--	--	--	510(499-522)2	426(200-598)10	540(500-590)5	470(200-598)17
2630	--	--	--	--	--	322(462-646)3	266(71-434)6	268(121-577)7	321(71-646)16
2650	--	--	--	--	266(231-317)3	220(130-372)12	228(153-325)12	219(120-353)11	226(120-372)38

*For full description of station locations, see Table 36.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B38. SUSPENDED SEDIMENTS (mg/1), 1972-78, AT SELECTED U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE POWDER RIVER BASIN

Station Number*	1972 $\bar{x}$ (min-max)n†	1973 $\bar{x}$ (min-max)n	1974 $\bar{x}$ (min-max)n	1975 $\bar{x}$ (min-max)n	1976 $\bar{x}$ (min-max)n	1977 $\bar{x}$ (min-max)n	1978 $\bar{x}$ (min-max)n
0550	47(6-244)13	50(4-188)10	51(7-306)11	178(7-1740)13	82(5-740)15	35(9-60)10	75(4-1740)75
0850	-	-	46(22-65)3	728(9-4360)13	385(28-1960)12	148(5-371)8	428(5-4360)36
1700	6048(272-25399)14	8918(179-39799)10	5392(292-33599)11	21400(-)1	15551(536-44499)5	20086(179-122000)69	
2650	-	-	791(180-1550)4	5310(31-19000)12	2973(139-9349)12	6583(131-34499)14	4636(31-34499)42
9494	-	-	5.9(-)1	97(8-280)12	56(20-133)7	55(8-140)5	73(6-280)25
9499	-	-	129(43-296)3	220(38-1100)13	82(13-161)12	132(39-311)7	147(13-1100)35
9600	-	-	506(114-1160)3	830(35-7239)13	158(78-316)12	328(78-842)9	464(35-7240)37

*For full description of station locations, see Table 35-36.
$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates
†the total number of samples collected.

APPENDIX C

PARAMETERS EXCEEDING WATER QUALITY CRITERIA

Contents of this appendix are organized by basin and station as described in Tables 34 through 36.

Those parameters for which water quality criteria have been exceeded in the study area during the years 1974-77 and the maximum parameter value observed during those years are listed for each station. Also presented are the number of violations observed for each parameter and beneficial use, and total number of data points collected per parameter during the specified time frame.

Those stations at which no criteria excesses were noted are not included in the appendix. Beneficial use codes presented represent the following: AL=aquatic life; DW=drinking water; I=irrigation; L=livestock.

TABLE C1. PARAMETERS EXCEEDING WATER QUALITY CRITERIA IN THE TONGUE AND POWDER RIVER BASINS, AND THEIR TOTAL NUMBER OF OBSERVED VIOLATIONS, 1974-77

	Number of Times Criteria Exceeded								
Stream, Station Number, and Beneficial Use	Cadmium	Iron	Lead	Manganese	Mercury	Sulfates	Aluminum	Chromium	Fluoride
Sarpy Creek									
9494									
AL	3	4	11	--	5	--	--	--	--
DW	10	6	11	8	--	27	--	--	--
I	10	1	--	4	--	--	--	--	--
L	--	--	11	--	--	--	--	--	--
Total number of values	11	11	11	11	11	28	7	11	--
Maximum excess value	20 ug/l	11,000 ug/l	100 ug/l	6,000 ug/l	0.3 ug/l	2,800 mg/l	--	--	--
Armells Creek									
9498									
AL	1	1	10	--	5	--	--	--	--
DW	10	7	10	7	--	29	--	--	--
I	10	--	--	5	--	--	--	--	--
L	10	--	10	--	--	--	--	--	--
Total number of values	10	10	10	10	10	30	8	10	--
Maximum excess value	20 ug/l	2,400 ug/l	100 ug/l	760 ug/l	0.4 ug/l	3,000 mg/l	--	--	--
9499									
AL	3	6	13	--	6	--	--	--	--
DW	13	11	13	12	--	35	--	1	--
I	13	2	--	4	--	--	1	--	--
L	--	--	13	--	--	--	1	--	--
Total number of values	13	13	13	13	13	35	8	12	--
Maximum excess value	20 ug/l	9,700 ug/l	100 ug/l	270 ug/l	0.6 ug/l	2,700 mg/l	5,400 ug/l	64 ug/l	--
Rosebud Creek									
9525									
AL	--	4	12	--	5	--	--	--	--
DW	11	12	12	7	--	29	--	--	--
I	11	1	--	4	--	--	1	--	--
L	--	--	12	--	--	--	1	--	--
Total number of values	12	12	12	12	12	40	8	12	--
Maximum excess value	10 ug/l	16,000 ug/l	100 ug/l	600 ug/l	0.3 ug/l	420 mg/l	8,800 ug/l	--	--
9535									
AL	--	1	1	--	1	--	--	--	--
DW	1	1	1	1	--	--	--	--	--
I	1	--	--	--	--	--	--	--	--
L	--	--	1	--	--	--	--	--	--
Total number of values	1	1	1	1	1	2	--	1	--
Maximum excess value	10 ug/l	2,300 ug/l	100 ug/l	70 ug/l	0.2 ug/l	--	--	--	--

TABLE C1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded								
	Cadmium	Iron	Lead	Manganese	Mercury	Sulfates	Aluminum	Chromium	Fluoride
9540									
AL	1	5	12	--	5	--	--	--	--
DW	11	12	12	5	--	30	--	--	--
I	11	2	--	3	--	--	--	--	--
L	--	--	12	--	--	--	--	--	--
Total number of values	12	12	12	12	12	36	8	11	--
Maximum excess value	20 ug/l	8,200 ug/l	100 ug/l	310 ug/l	0.4 ug/l	560 mg/l	--	--	--
9550									
AL	--	9	12	--	7	--	--	--	--
DW	9	12	12	7	--	26	--	--	--
I	9	5	--	4	--	--	2	--	--
L	--	--	12	--	--	--	2	--	--
Total number of values	12	12	12	12	12	32	8	12	--
Maximum excess value	10 ug/l	11,000 ug/l	100 ug/l	420 ug/l	1.2 ug/l	600 mg/l	7,300 ug/l	--	--
9600									
AL	1	13	13	--	7	--	--	--	--
DW	12	13	13	13	--	35	--	--	--
I	12	4	--	4	--	--	--	--	--
L	--	--	13	--	--	--	--	--	--
Total number of values	13	13	13	13	13	41	8	13	--
Maximum excess value	20 ug/l	32,000 ug/l	100 ug/l	570 ug/l	1.2 ug/l	620 mg/l	--	--	--
Tongue River									
9800									
AL	--	2	9	--	2	--	--	--	--
DW	8	2	9	1	--	--	--	--	--
I	8	--	--	--	--	--	--	--	--
L	--	--	9	--	--	--	--	--	--
Total number of values	9	33	10	9	9	101	10	9	--
Maximum excess value	10 ug/l	750 ug/l	100 ug/l	80 ug/l	0.6 ug/l	--	--	--	--
9998									
AL	--	1	11	--	--	--	--	--	--
DW	9	4	11	1	--	--	--	--	--
I	9	--	--	--	--	--	--	--	--
L	--	--	11	--	--	--	--	--	--
Total number of values	11	11	12	11	11	50	12	11	--
Maximum excess value	10 ug/l	1,800 ug/l	100 ug/l	60 ug/l	--	--	--	--	--

TABLE C1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded								
	Cadmium	Iron	Lead	Manganese	Mercury	Sulfates	Aluminum	Chromium	Fluoride
0550									
AL	--	1	10	--	1	--	--	--	--
DW	9	5	10	6	--	2	--	--	--
I	9	--	--	--	--	--	1	--	--
L	--	--	10	--	--	--	1	--	--
Total number of values	10	29	11	10	10	100	11	10	--
Maximum excess value	10 ug/l	1,600 ug/l	100 ug/l	80 ug/l	1.0 ug/l	260 mg/l	6,000 ug/l	--	--
0610									
AL	--	2	7	--	2	--	--	--	--
DW	6	7	7	7	--	18	--	1	--
I	6	1	--	--	--	--	--	--	--
L	--	--	7	--	--	--	--	--	--
Total number of values	7	7	7	7	7	26	7	7	--
Maximum excess value	10 ug/l	6,900 ug/l	100 ug/l	190 ug/l	0.2 ug/l	350 mg/l	--	66 ug/l	--
0630									
AL	--	1	11	--	1	--	--	--	--
DW	10	8	11	7	--	3	--	--	--
I	10	--	--	1	--	--	--	--	--
L	--	--	11	--	--	--	--	--	--
Total number of values	11	11	12	11	11	52	12	11	--
Maximum excess value	10 ug/l	4,800 ug/l	100 ug/l	210 ug/l	0.1 ug/l	300 mg/l	--	--	--
0680									
AL	1	2	4	--	2	--	--	--	--
DW	4	3	4	4	--	8	--	1	--
I	4	1	--	2	--	--	--	--	--
L	--	--	4	--	--	--	--	--	--
Total number of values	4	4	4	4	4	10	3	4	--
Maximum excess value	30 ug/l	5,000 ug/l	200 ug/l	850 ug/l	0.2 ug/l	3,200 mg/l	--	60/ug l	--
0750									
AL	--	--	7	--	2	--	--	--	--
DW	6	4	7	5	--	1	--	--	--
I	6	--	--	--	--	--	--	--	--
L	--	--	7	--	--	--	--	--	--
Total number of values	7	7	7	7	7	26	7	7	--
Maximum excess value	10 ug/l	550 ug/l	100 ug/l	90 ug/l	0.1 ug/l	260 ug/l	--	--	--

TABLE C1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded								
	Cadmium	Iron	Lead	Manganese	Mercury	Sulfates	Aluminum	Chromium	Fluoride
0760									
AL	3	5	13	--	4	--	--	--	--
DW	13	13	13	9	--	37	--	--	--
I	13	1	--	3	--	--	--	--	--
L	--	--	13	--	--	--	--	--	--
Total number of values	13	13	13	13	13	40	8	13	--
Maximum excess value	20 ug/l	5,700 ug/l	100 ug/l	390 ug/l	0.4 ug/l	1,500 mg/l	--	--	--
0761									
AL	--	1	15	--	5	--	--	--	--
DW	10	5	15	4	--	7	--	--	--
I	10	--	--	--	--	--	--	--	1
L	--	--	15	--	--	--	--	--	--
Total number of values	10	10	15	10	15	45	15	10	4
Maximum excess value	10 ug/l	1,400 ug/l	100 ug/l	80 ug/l	0.6 ug/l	420 mg/l	--	--	1.1 mg/l
0761-5									
AL	1	2	12	--	3	--	--	--	--
DW	11	7	12	9	--	33	--	--	--
I	11	--	--	--	--	--	--	--	--
L	--	--	12	--	--	--	--	--	--
Total number of values	12	12	12	12	12	34	7	12	--
Maximum excess value	30 ug/l	2,500 ug/l	100 ug/l	140 ug/l	0.2 ug/l	670 mg/l	--	--	--
0767									
AL	--	1	1	--	--	--	--	--	--
DW	1	1	1	1	--	2	--	--	--
I	1	--	--	--	--	--	--	--	--
L	--	--	1	--	--	--	--	--	--
Total number of values	1	1	1	1	1	5	--	1	--
Maximum excess value	10 ug/l	1,600 ug/l	100 ug/l	110 ug/l	--	1,300 mg/l	--	--	--
0774									
AL	--	6	12	--	5	--	--	--	--
DW	12	10	12	9	--	37	--	1	--
I	12	--	--	1	--	--	--	--	--
L	--	--	12	--	--	--	--	--	--
Total number of values	12	12	12	12	12	39	7	12	--
Maximum excess value	10 ug/l	2,900 ug/l	100 ug/l	360 ug/l	0.8 ug/l	1,500 mg/l	--	90 ug/l	--

TABLE C1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded								
	Cadmium	Iron	Lead	Manganese	Mercury	Sulfates	Aluminum	Chromium	Fluoride
0781									
AL	1	1	3	--	--	--	--	--	--
DW	3	2	3	2	--	7	--	--	--
I	3	--	--	--	--	--	--	--	--
L	--	--	3	--	--	--	--	--	--
Total number of values	3	3	3	3	3	9	2	3	--
Maximum excess value	20 ug/l	1,600 ug/l	100 ug/l	140 ug/l	--	2,000 mg/l	--	--	--
0783									
AL	--	3	14	--	8	--	--	--	--
DW	11	7	14	4	--	15	--	--	--
I	11	2	--	1	--	--	1	--	--
L	--	--	14	--	--	--	1	--	--
Total number of values	12	12	14	11	14	37	11	12	1
Maximum excess value	10 ug/l	13,000 ug/l	100 ug/l	300 ug/l	0.5 ug/l	390 mg/l	6,000 ug/l	--	--
0784									
AL	--	--	1	--	--	--	--	--	--
DW	1	1	1	--	--	--	--	--	--
I	1	--	--	--	--	--	--	--	--
L	--	--	1	--	--	--	--	--	--
Total number of values	1	1	1	1	1	3	--	1	--
Maximum excess value	10 ug/l	1,700 ug/l	100 ug/l	--	--	--	--	--	--
0816									
AL	--	1	3	--	--	--	--	--	--
DW	3	3	3	3	--	13	--	--	--
I	3	--	--	2	--	--	--	--	--
L	--	--	3	--	--	--	--	--	--
Total number of values	3	3	3	3	3	13	3	3	--
Maximum excess value	10 ug/l	1,200 ug/l	100 ug/l	4,500 ug/l	--	4,000 mg/l	--	--	--
0817									
AL	--	--	--	--	--	--	--	--	--
DW	--	--	--	--	--	6	--	--	--
I	--	--	--	--	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--
Total number of values	--	--	--	--	--	6	--	--	--
Maximum excess value	--	--	--	--	--	2,300 mg/l	--	--	--

TABLE C1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded								
	Cadmium	Iron	Lead	Manganese	Mercury	Sulfates	Aluminum	Chromium	Fluoride
0819									
AL	--	--	1	--	--	--	--	--	--
DW	1	1	1	1	--	9	--	--	--
I	1	--	--	--	--	--	--	--	--
L	--	--	1	--	--	--	--	--	--
Total number of values	1	1	1	1	1	9	1	1	--
Maximum excess value	10 ug/l	380 ug/l	100 ug/l	150 ug/l		3,600 mg/l	--	--	--
0840									
AL	1	1	5	--	3	--	--	--	--
DW	4	4	5	4	--	10	--	--	--
I	4	--	--	--	--	--	--	--	--
L	--	--	5	--	--	--	--	--	--
Total number of values	5	5	5	5	5	15	5	5	--
Maximum excess value	20 ug/l	4,200 ug/l	200 ug/l	120 ug/l	0.2 ug/l	1,700 mg/l	--	--	--
0850									
AL	--	5	7	--	1	--	--	--	--
DW	8	5	7	3	--	11	--	3	--
I	8	1	--	1	--	--	--	--	--
L	--	--	7	--	--	--	--	--	--
Total number of values	15	15	17	14	16	100	3	15	2
Maximum excess value	20 ug/l	74,000 ug/l	100 ug/l	680 ug/l	0.8 ug/l	440 mg/l	--	80 ug/l	--
Powder River									
1250									
AL	--	--	--	--	--	--	--	--	--
DW	--	--	--	--	--	42	--	--	--
I	--	--	--	--	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--
Total number of values	--	--	--	--	--	49	--	--	--
Maximum excess value	--	--	--	--	--	672 mg/l	--	--	--
1300									
AL	2	7	9	--	4	--	--	1	--
DW	9	8	9	8	1	36	--	3	--
I	--	5	8	4	--	--	5	1	--
L	1	--	9	--	--	--	5	--	--
Total number of values	9	9	9	9	9	36	9	9	--
Maximum excess value	60 ug/l	810,000 ug/l	900 ug/l	11,000 ug/l	2.1 ug/l	2,300 mg/l	360,000 ug/l	500 ug/l	--

TABLE C1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded								
	Cadmium	Iron	Lead	Manganese	Mercury	Sulfates	Aluminum	Chromium	Fluoride
1340									
AL	1	7	7	--	1	--	--	2	--
DW	7	7	7	7	--	49	--	2	--
I	7	6	--	4	--	--	1	2	--
L	--	--	7	--	--	--	1	--	--
Total number of values	10	10	10	10	9	49	10	10	--
Maximum excess value	20 ug/l	400,000 ug/l	600 ug/l	6,400 ug/l	0.3 ug/l	1,900 mg/l	170,000 ug/l	320 ug/l	--
1350									
AL	--	2	2	--	--	--	--	--	--
DW	2	2	2	2	--	7	--	--	--
I	2	1	--	--	--	--	1	--	--
L	--	--	2	--	--	--	1	--	--
Total number of values	2	2	2	2	2	7	1	2	--
Maximum excess value	10 ug/l	8,500 ug/l	100 ug/l	160 ug/l	--	950 mg/l	6,900 ug/l	--	--
1640									
AL	--	2	2	--	--	--	--	--	--
DW	2	2	2	2	--	49	--	--	--
I	2	1	--	--	--	--	--	--	--
L	--	--	2	--	--	--	--	--	--
Total number of values	2	2	2	2	2	49	1	2	--
Maximum excess value	10 ug/l	5,200 ug/l	100 ug/l	190 ug/l	--	1,500 mg/l	--	--	--
1700									
AL	1	1	1	--	1	--	--	1	--
DW	1	1	1	1	--	52	--	1	--
I	1	1	--	1	--	--	1	1	--
L	--	--	1	--	--	--	1	--	--
Total number of values	1	1	1	1	1	52	1	1	--
Maximum excess value	30 ug/l	310,000 ug/l	400 ug/l	5,000 ug/l	0.7 ug/l	1,500 mg/l	180,000 ug/l	300 ug/l	--
2020									
AL	--	1	9	--	1	--	--	--	--
DW	9	3	9	6	--	24	--	--	--
I	9	--	--	--	--	--	--	--	--
L	--	--	9	--	--	--	--	--	--
Total number of values	10	10	10	10	10	33	10	10	--
Maximum excess value	10 ug/l	1,200 ug/l	100 ug/l	150 ug/l	0.1 ug/l	490 mg/l	--	--	--

TABLE C1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded								
	Cadmium	Iron	Lead	Manganese	Mercury	Sulfates	Aluminum	Chromium	Fluoride
2040									
AL	--	3	9	--	--	--	--	--	--
DW	9	5	9	9	--	27	--	--	--
I	9	--	--	--	--	--	--	--	--
L	9	--	9	--	--	--	--	--	--
Total number of values	10	10	10	10	10	27	10	10	--
Maximum excess value	10 ug/l	1,900 ug/l	100 ug/l	190 ug/l	--	670 mg/l	--	--	--
2350									
AL	--	--	12	--	3	--	--	--	--
DW	12	6	12	2	--	1	--	--	--
I	12	--	--	--	--	--	--	--	--
L	--	--	12	--	--	--	--	--	--
Total number of values	12	12	12	12	12	35	12	12	--
Maximum excess value	10 ug/l	940 ug/l	100 ug/l	100 ug/l	1.0 ug/l	290 mg/l	--	--	--
2400									
AL	--	3	11	--	2	--	--	--	--
DW	10	9	11	8	1	41	--	--	--
I	10	1	--	1	--	--	1	--	--
L	--	--	11	--	--	--	1	--	--
Total number of values	11	11	12	11	11	50	13	11	--
Maximum excess value	10 ug/l	21,000 ug/l	100 ug/l	420 ug/l	2.0 ug/l	830 mg/l	11,000 ug/l	--	--
2450									
AL	1	11	14	--	9	--	--	2	--
DW	3	12	14	8	--	77	--	2	--
I	3	8	--	8	--	--	9	2	--
L	--	--	14	--	--	--	9	--	--
Total number of values	12	12	14	11	12	77	11	13	--
Maximum excess value	20 ug/l	600,000 ug/l	800 ug/l	9,700 ug/l	1.1 ug/l	1,300 mg/l	270,000 ug/l	500 ug/l	--
2492									
AL	--	5	7	--	2	--	--	--	--
DW	7	6	6	7	--	10	--	--	--
I	7	1	--	1	--	--	--	--	--
L	--	--	6	--	--	--	--	--	--
Total number of values	7	6	7	7	6	10	6	7	--
Maximum excess value	10 ug/l	8,100 ug/l	100 ug/l	230 ug/l	0.1 ug/l	1,900 mg/l	--	--	--

TABLE C1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded								
	Cadmium	Iron	Lead	Manganese	Mercury	Sulfates	Aluminum	Chromium	Fluoride
2497									
AL	--	26	29	--	7	--	--	--	--
DW	30	28	29	30	--	75	--	--	--
I	30	1	--	23	--	--	5	--	--
L	--	--	29	--	--	--	5	--	--
Total number of values	30	30	30	30	30	75	30	30	--
Maximum excess value	10 ug/l	63,000 ug/l	200 ug/l	1,400 ug/l	1.4 ug/l	2,100 mg/l	68,000 ug/l	100 ug/l	--
2605									
AL	--	--	3	--	--	--	--	--	--
DW	3	1	3	3	--	12	--	--	--
I	3	1	--	1	--	--	--	--	--
L	--	--	3	--	--	--	--	--	--
Total number of values	3	3	3	3	3	12	3	3	--
Maximum excess value	10 ug/l	940 ug/l	100 ug/l	7,100 ug/l		3,200 mg/l	--	--	--
2620									
AL	1	--	5	--	1	--	--	--	--
DW	5	4	5	5	--	17	--	--	--
I	5	--	--	4	--	--	--	--	--
L	--	--	5	--	--	--	--	--	--
Total number of values	5	5	5	5	5	17	5	5	--
Maximum excess value	20 ug/l	990 ug/l	100 ug/l	1,700 ug/l	0.1 ug/l	1,300 mg/l	--	--	--
2630									
AL	1	3	6	--	2	--	--	1	--
DW	6	6	6	5	--	13	--	1	--
I	6	2	--	1	--	--	1	1	--
L	--	--	6	--	--	--	1	--	--
Total number of values	6	6	6	6	5	18	6	6	--
Maximum excess value	20 ug/l	74,000 ug/l	200 ug/l	970 ug/l	0.3 ug/l	1,300 mg/l	54,000 ug/l	130 ug/l	--
2650									
AL	1	13	13	--	11	--	--	2	--
DW	13	14	13	11	--	39	--	3	--
I	13	10	--	9	--	--	--	2	--
L	--	--	13	--	--	--	--	--	--
Total number of values	14	14	14	14	13	40	--	14	--
Maximum excess value	20 ug/l	300,000 ug/l	400 ug/l	5,600 ug/l	0.4 ug/l	1,200 mg/l	--	220 ug/l	--

TABLE C1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded									
	Dissolved Oxygen	Copper	Beryllium	Chloride	Nickel	Selenium	Zinc	Boron	Molybdenum	Arsenic
Sarpy Creek										
9494										
AL	3	--	--	--	--	--	--	--	--	--
DW	--	--	--	--	--	--	--	--	--	--
I	--	--	--	--	--	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	28	11	11	28	11	11	7	--	11	11
Maximum excess value	1.8 mg/l	--	--	--	--	--	--	--	--	--
Armells Creek										
9499										
AL	--	--	1	--	--	--	--	--	--	--
DW	--	--	--	1	--	--	--	--	--	--
I	--	1	--	--	--	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	35	13	13	35	13	13	8	--	13	13
Maximum excess value	--	300 ug/l	20 ug/l	--	--	--	--	--	--	--
Tongue River										
0767										
AL	1	--	--	--	--	--	--	--	--	--
DW	--	--	--	--	--	--	--	--	--	--
I	--	--	--	--	--	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	5	1	1	5	1	1	--	--	1	1
Maximum excess value	3.0 mg/l	--	--	--	--	--	--	--	--	--
0816										
AL	6	--	--	--	--	--	--	--	--	--
DW	--	--	--	--	--	--	--	--	--	--
I	--	--	--	--	--	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	13	3	3	13	3	3	3	--	3	3
Maximum excess value	0.0 mg/l	--	--	--	--	--	--	--	--	--
Powder River										
1300										
AL	--	--	--	--	--	--	--	--	--	--
DW	--	--	--	1	--	7	--	--	--	2
I	--	2	--	--	2	3	--	--	--	1
L	--	1	--	--	--	--	--	--	--	--
Total number of values	24	9	9	36	9	9	9	18	9	9
Maximum excess value	--	790 ug/l	20 ug/l	280 mg/l	450 ug/l	28 ug/l	4,500 ug/l	--	--	180 ug/l

TABLE C1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded									
	Dissolved Oxygen	Copper	Beryllium	Chloride	Nickel	Selenium	Zinc	Boron	Molybdenum	Arsenic
1340										
AL	3	--	--	--	--	--	--	--	--	--
DW	--	--	--	39	--	--	--	--	--	--
I	--	2	--	--	2	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	26	10	10	49	10	10	10	--	10	10
Maximum excess value	0.7	390 ug/l	20 ug/l	1,600 mg/l	500 ug/l	--	--	--	--	--
1350										
AL	--	--	--	--	--	--	--	--	--	--
DW	--	--	--	6	--	--	--	--	--	--
I	--	--	--	--	--	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	8	2	1	7	2	1	2	--	1	1
Maximum excess value	--	--	--	970 mg/l	--	--	--	--	--	--
1700										
AL	1	--	--	--	--	--	--	--	--	--
DW	--	--	--	30	--	1	--	--	--	--
I	--	1	--	--	1	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	20	1	1	52	1	1	1	--	1	1
Maximum excess value	2.9 mg/l	300 ug/l	20 ug/l	543 mg/l	500 ug/l	12 ug/l	--	--	--	--
2400										
AL	--	--	--	--	--	--	--	--	--	--
DW	--	--	--	--	--	--	--	--	--	--
I	--	--	--	--	--	--	--	1	--	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	47	12	11	50	11	13	12	29	11	11
Maximum excess value	--	--	--	--	--	--	--	930 ug/l	--	--
2450										
AL	2	--	--	--	--	--	--	--	--	--
DW	--	--	--	3	--	--	--	--	--	2
I	--	2	--	--	--	--	1	--	--	2
L	--	2	--	--	--	--	--	--	--	2
Total number of values	82	14	12	74	12	14	11	2	12	12
Maximum excess value	3.0 ug/l	900 ug/l	20 ug/l	320 mg/l	650 ug/l	--	2,700 ug/l	--	--	350 ug/l

TABLE C1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded									
	Dissolved Oxygen	Copper	Beryllium	Chloride	Nickel	Selenium	Zinc	Boron	Molybdenum	Arsenic
2492										
AL	--	--	--	--	--	--	--	--	--	--
DW	--	--	--	--	--	--	--	--	--	--
I	--	--	--	--	--	--	--	1	1	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	10	7	7	10	7	6	6	1	7	6
Maximum excess value	--	--	20 ug/l	--	--	--	--	1,700 ug/l	53 ug/l	--
2497										
AL	--	--	--	--	--	--	--	--	--	--
DW	--	--	--	--	--	--	--	--	--	3
I	--	--	--	--	--	--	--	--	1	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	64	30	30	75	30	30	30	1	30	30
Maximum excess value	--	--	20 ug/l	--	--	--	--	--	13 ug/l	90 ug/l
2605										
AL	6	--	--	--	--	--	--	--	--	--
DW	--	--	--	--	--	--	--	--	--	--
I	--	--	--	--	--	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	12	3	3	12	3	3	3	--	3	3
Maximum excess value	0.0 ug/l	--	--	--	--	--	--	--	--	--
2620										
AL	2	--	--	--	--	--	--	--	--	--
DW	--	--	--	--	--	--	--	--	--	--
I	--	--	--	--	--	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	17	5	5	17	5	5	5	--	5	5
Maximum excess value	3.0 ug/l	--	--	--	--	--	--	--	--	--
2630										
AL	--	--	--	--	--	--	--	--	--	--
DW	--	--	--	--	--	--	--	--	--	--
I	--	--	--	--	--	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	18	6	5	18	6	5	5	1	6	5
Maximum excess value	--	--	20 ug/l	--	--	--	--	--	--	--

TABLE C1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded									
	Dissolved Oxygen	Copper	Beryllium	Chloride	Nickel	Selenium	Zinc	Boron	Molybdenum	Arsenic
2650										
AL	1	--	--	--	--	--	--	--	--	--
DW	--	--	--	--	--	--	--	--	--	2
I	--	1	--	--	--	--	--	--	--	--
L	--	--	--	--	--	--	--	--	--	--
Total number of values	40	14	--	40	--	14	14	--	--	14
Maximum excess value	2.7 ug/l	390 ug/l	--	--	--	--	--	--	--	92 ug/l

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16. ABSTRACT

The Tongue and Powder River Basins contain vast beds of low-sulfur, stripable coal that potentially will support a large number of powerplants, gasification, and liquefaction complexes for conversion of this coal into commercially usable power. Development of local oil and gas fields, as well as some uranium exploration, is also ongoing. However, utilization of these energy resources, especially if maximum levels of expansion are realized, is expected to have considerable impact on water resources in the Tongue and Powder River Basins. It appears unlikely that there are sufficient surface or ground water supplies to meet projected needs in the area without creation of additonal reservoir storage or diversion of surface water from other sources. Water quality and quantity impacts from energy developments will reduce water usability for municipal, industrial, and irrigation purposes and will have adverse impacts on the aquatic ecosystem. Alternative proposals for maintenance of valid instream flow requirements in the basins, however, could greatly limit annual quantities of water available for diversion for energy users. The existing U.S. Geological Survey sampling network is adequately situated for evaluating the impact of energy development activities and should be carefully monitored on a regular basis in the future. Priority listings of parameters to be measured to detect changes in water quality as a result of energy resource development and to assess future projects are recommended.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Coal	Monitoring	08H,I
Strip mining	Tongue River	13B
Water resources	Powder River	17B
Water quality	Rosebud Creek	21D
Electric power generation	Sarpy Creek	97R
	Armells Creek	

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